Design and Fabrication of Active SEMG Sensor for Prosthesis Control

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DEC, 2015

Declaration

I certify that this research work titled "*Design and Fabrication of Active SEMG Sensor for Prosthesis Control*" is my own work. The work has not been presented elsewhere for assessment. The material that has been used from other sources it has been properly acknowledged / referred.

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Language Correctness Certificate

This thesis has been read by an English expert and is free of typing, syntax, semantic, grammatical and spelling mistakes. Thesis is also according to the format given by the university.

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Copyright Statement

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First of all, I am thankful to my Creator Allah Subhana-Watala, Who guided me throughout this work at every step and for every new thought which came into my mind to improve it. Indeed I could have done nothing without precious help and shear guidance of Allah. Whosoever helped me throughout the course of my thesis, whether my wife or any other individual was because of Allah's will, so indeed none be worthy of praise but Allah.

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Abstract

Skeletal muscles are the key source of our body motion. To perform any activity, messages are transmitted from brain to specific muscle through motor neurons. Muscles are tied up to the bones via tough cords of tissues and these cords are called tendons. As the muscle contracts, it pulls on the tendon, and resultantly cause the bone to move. Contraction of muscle is due to nerve impulse stimulation. Because of stimulation, exchange of ions across the muscle fiber occurred, which result in generation of small electrical current, which combined for a specific motor unit, is known as the Motor Unit Action Potential (MUAP). Combination of all electrical signals generated from all of the MUAPs in a detected area is called myoelectric signal. This signal is known as Electromyogram (EMG).

Humans with amputations due to mishaps (wars/accidents) or inborn absence, are forced to use prosthesis. Two types of prosthesis are being used worldwide, passive and active but latter one is more expensive but considered as substitute to natural limbs to some extent. To control myoelectric prosthesis, SEMG signals are picked up through surface electrodes (dry/wet). Multiple active/passive SEMG sensors have been developed and are being used worldwide to control it. Each type has its own merits/demerits. To get noise free EMG signal, this thesis research has focused to develop active SEMG sensor, which could control myoelectric prosthesis effectively. A novel simulink model is developed, which mimics various elements of an active SEMG sensor. By using this model, low/high/notch filters are designed and optimized, which are used in signal conditioning of raw signal acquired from SEMG sensor. Finally, on the basis of successful simulation results, instrumentation of surface EMG sensor (38mmx24mmx 7mm) is designed and fabricated using Altium Designer 14. Pure silver electrodes (17mmx5mmx1mm) are used as dry electrodes and are directly connected to Pre-amplifier (INA118). Results of the Simulink model and developed SEMG sensor have shown close resemblance, therefore, the model will be used for further research in domain of electromyogram.

Key Words: *Electromyographic (EMG), power spectral density (PSD), surface EMG (SEMG), Biomedical Simulink modeling.*

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CHAPTER 1: INTRODUCTION

The research work presented in this dissertation is about design and fabrication of active SEMG sensor for prosthesis control. Main purpose of this sensor is acquisition of SEMG signal, its conditioning and amplification. Researchers are putting their best in this field to help amputee persons by acquiring high quality EMG signal as a result of muscle twitching due to nerve impulses. In this chapter, generation of biopotential signal is discussed. Different parameters including multiple noise sources, which affect the SEMG signal acquisition, are also discussed.

1.1 Background

Muscles are the main source of our body motion. It is impossible for us to perform any activity without our muscles. They are the main source, which transform energy into motion. All activities of our body are performed when muscles are contracted or relaxed. All neural signals compel our muscles to perform desired actions. Activities performed due to muscle actions may range from pumping of blood from our heart to different multidimensional moves of our different body parts. Messages transmitted from brain are called nerve messages. Motor neurons are the main source of transmission of these nerve messages and cause the muscles to contract. During contraction phase, length of muscle will be generally shorten to about 57% of their original length and may enhance up to 70% against high strength signal [1]. Motor neuron, axon, and all of the muscle fibers form part of motor unit. Motor unit is established, when the brain takes decision to move any organ of body.

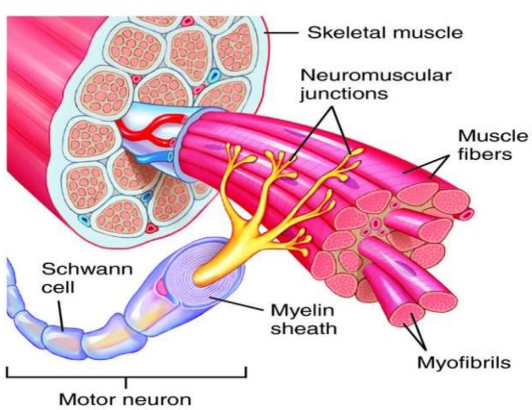

Figure 1.1 Motor neuron [1]

Nerve impulse is transmitted through motor neuron from brain to desired muscle, which stimulates the contraction of muscle. Motor neuron is actually a bundle of wires. Motor neuron is further divided into numerous branches named as axon terminals near to a muscle and each served different muscle fiber. Finally motor unit is combination of each motor neuron and the muscle fibers, which it stimulates as view in Figure 1.1. A motor unit consists of a motor neuron and the skeletal muscle fibers and same is innervated by that motor neuron's axonal terminals [2]. Contraction of a single muscle is even coordinated by groups of motor units. These motor units within a muscle are termed as motor pool. Fiber type is same for all muscle fibers in a motor unit is same. When a motor unit is actuated due to motor neuron, all of its fibers contract. However, the force of a muscle contraction depends upon the number of activated motor units.

Innervations zone is a place, where distribution of nerves to an organ is connected [3]. An axon is fiber, consists of nerves. It is long, slender projection of a nerve cell. Its prime function is to conducts electrical impulses away from the neuron's cell body. The major function of the axon is to transmit neural instructions to different neurons, muscles and glands of human body. The electrical impulse travels along an axon from the periphery to the cell body of sensory neurons and further from the cell body to the spinal cord along another branch of the same axon.

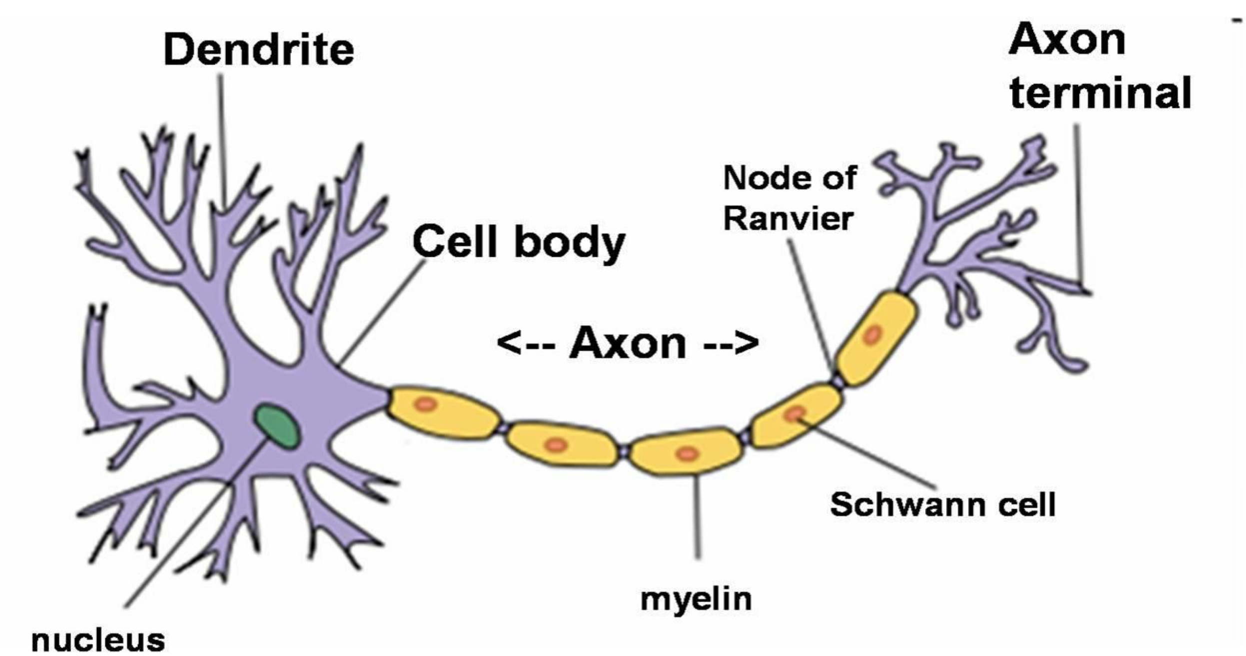

Figure 1.2 Axon [2]

1.2 Electromyogram (EMG)

Travelling wave of depolarization is the actual source of impulses conduction by nerves along their axon. Depolarization waves will transmit in the both direction from that point, when electrical stimulation of the nerve generated. Small electrical current is generated due to exchange of ions across the muscle fibers, which combined for a specific motor unit, is known as the Motor Unit Action Potential (MUAP) [3]. Combination of all electrical signals generated from all of the MUAPs in a detected area is called myoelectric signal, which is also referred as electromyogram (EMG) [4]. If certain muscle is required to generate force, then Central Nervous System is responsible for continuous activation of this muscle. Due to this continuous activation, motor unit action potential train is generated. Motor unit actional potential then superimpose to produce the resultant EMG signal. The electromyogram is used for diagnosing neuromuscular diseases.

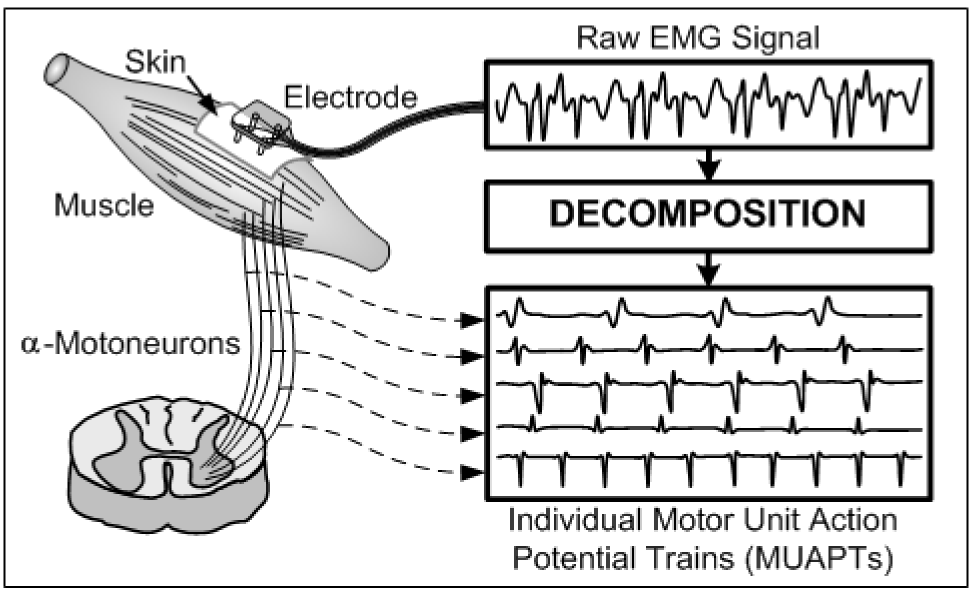

Figure 1.3 Raw EMG signal decomposition [3]

1.3 Human Body Cell Functioning

During contraction of muscle, current is generated, which is a proof that neuromuscular activity is being performed. This generated signal is a biomedical signal, which is acquired from skeleton muscle of any part of body when it contracts. The human body comprises of several tissues. Some of the tissues of human body such as heart muscles, skeleton muscles, smooth muscles and nervous tissues create electrochemical energy. The cells of such tissues contain ions like Na^+, K^+, Ca^+ and Cl^-. Difference of measure of ionic concentrations of each cell causes generation of Electro-chemical signals from the cells of these tissues. Under normal conditions, when cells are at rest they have a greater concentration of K^+ inside the cell where as higher concentration of Na^+ outside the cell. Within the cell, different ion channels exist which allowed specific ions to travel to and from the cell.

Ion channels exist in human body are basically pores proteins. These channels are responsible to establish voltage gradient across the plasma membrane of cells. This happened due to controlling the flow of ions down their electrochemical gradient.

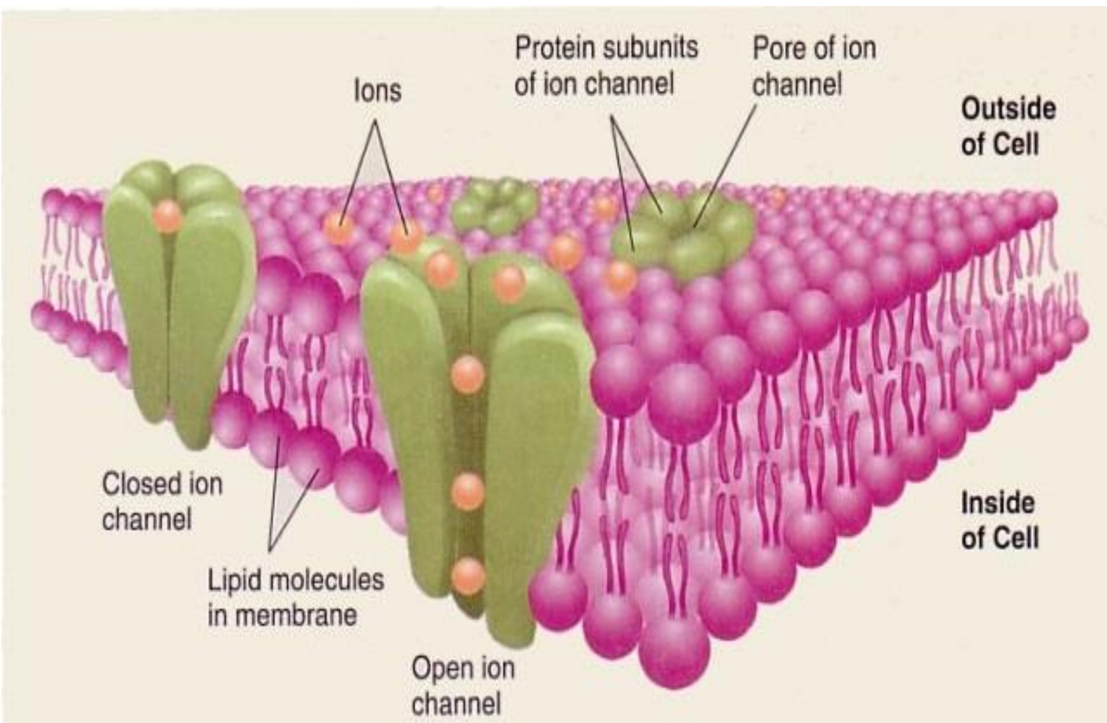

Figure 1.4 Ion channels in human body cell [4]

Any movement of electric charges, including ions is key source of an electric current generation. Thus, movement of sodium ions across a cell membrane constitutes an electric current.

Durin passive transportation, solutes move passively down concentration gradient such as Lipid solubility (oxygen and carbon dioxide), Protein channel (water) and facilitated transport (glucose).

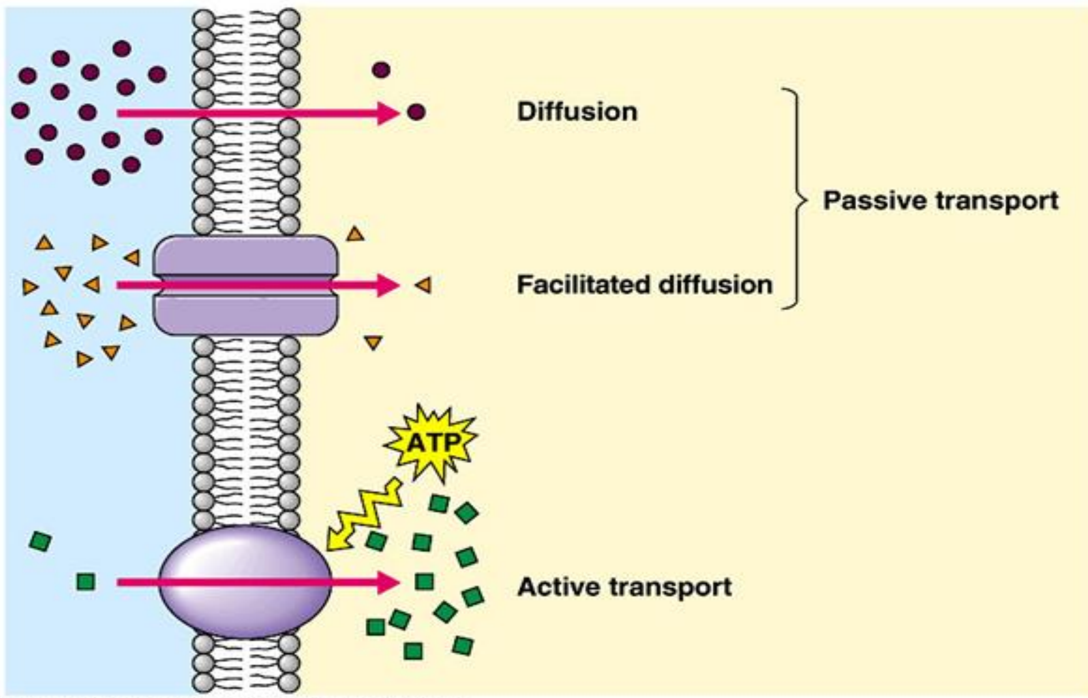

Figure 1.5 Active and passive transportation of ions across cell membrane [5]

During Active transportation, ions movement from near the cell membrane is carried out by carrier proteins, carry them on the other side of membrane and release them. In this whole process, energy is mandatory to complete this task.

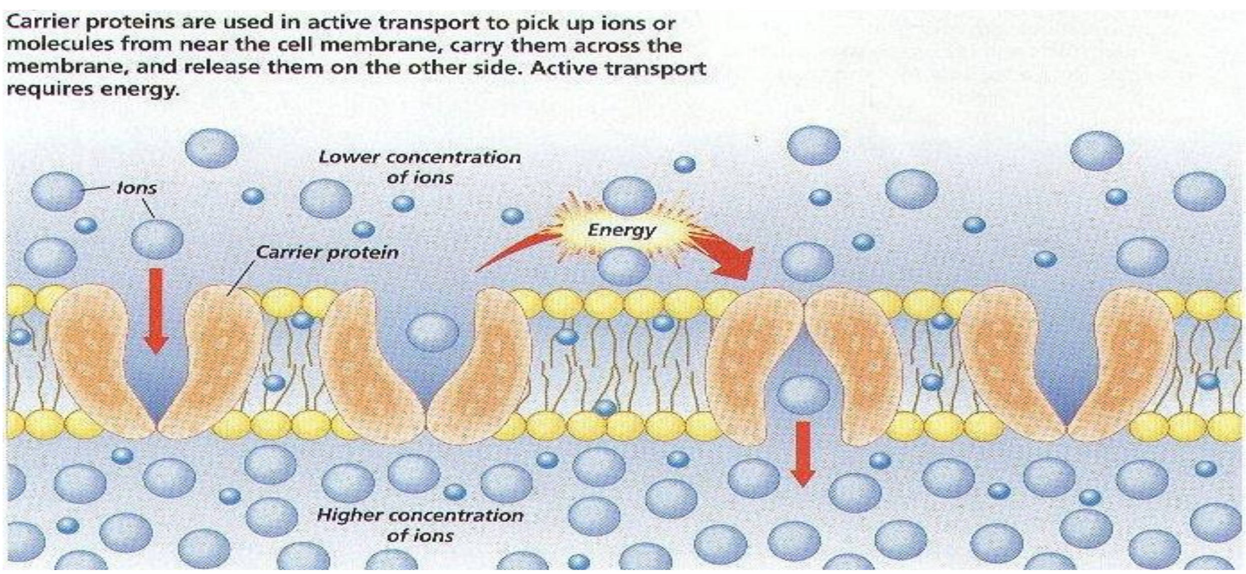

Figure 1.6 Carrier proteins and channel proteins [6]

During Active transportation of Ions, Na-K pump is used. During resting phase, concentration of Na+ is more outside of cell where as concentration of K+ is more inside the cell. It maintains low Na+ concentration inside cell where as K+ leaks back out by concentration gradient 100 times faster than Na+ comes back in. It maintains voltage gradient inside negative and outside positive.

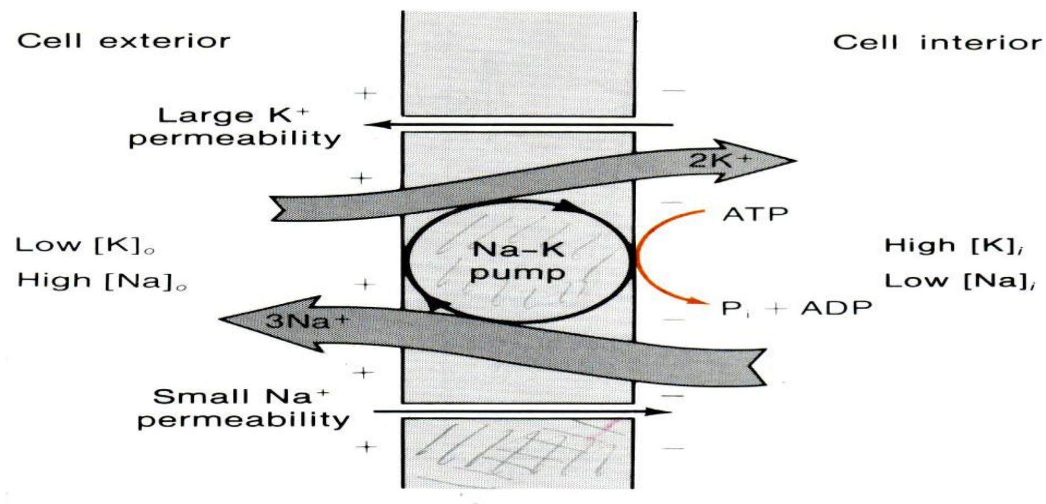

Figure 1.7 Na – K Pump functioning

During this pumping action, three Na^+ ions are pumped out of it while two K^+ ions are pumped into the cell. Resultantly, more positive ions leave than enter, which makes the cell more negative inside with respect to interstitial medium. The cell in resting stage thus has more K^+ ions inside it and is at negative potential. It is said to be polarized.

1.4 Major Types of Muscles in Human Body

Every action, which our brain conceives, and desires to act, is expressed in terms of muscular motion. Each and every feeling of human is generally expressed by different muscles of human body such as the muscles of hands, legs, foot, mouth, eyes, face and tongue. Muscles not only act in supporting role but also restrict movement of joint in wrong direction. Although more than 600 muscles exist in our body but they are generally classified into only three types of muscle: smooth, cardiac and skeletal. They help us to perform any desired task efficiently.

1.4.1 Skeletal Muscles

Skeletal muscles are called voluntary muscles since human has control over them and can contract as and when desired. These muscles play key role in body movement. Approximately 640 skeletal muscles exist in our body and each muscle constitutes a pair of identical bilateral muscles, which are present on both sides of a joint. Hence 320 pairs of muscles do exist. Two or multiple groups of skeletal muscle antagonize each other. It means that when one contracts, the other(s) elongates. Tough cords of tissues, called tendons, are used to tie up muscles. When muscle's contraction takes place, it pulls on the tendon, which moves the bone. Hence these muscles on the other hand support the skeleton. These muscles contribute to approximately half of the body mass of human.

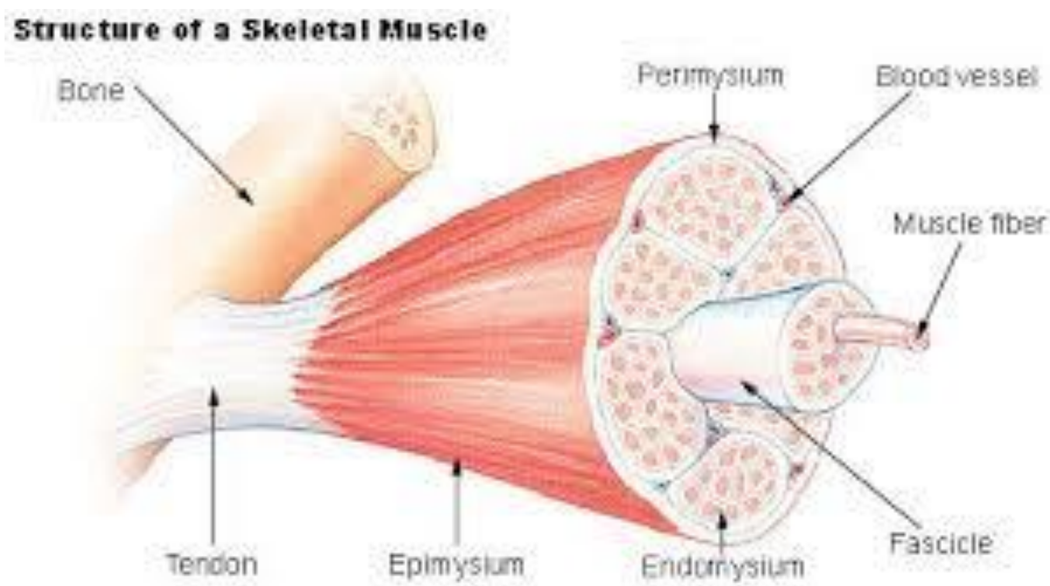

Figure 1.8 Skeletal muscle [7]

1.4.2 Smooth Muscles

Smooth muscles are involuntary muscles as human has no control over them. Muscles of stomach, small intestine, large intestine, walls of blood vessel and bladder are smooth muscles. These are found within the walls of organs. Smooth muscle sustains stretch and maintains tension for longer periods of time. They are innervated by autonomic nervous system and therefore, are not under voluntary control and respond slowly to stimuli. Smooth muscles are involuntarily and contracts at their own.

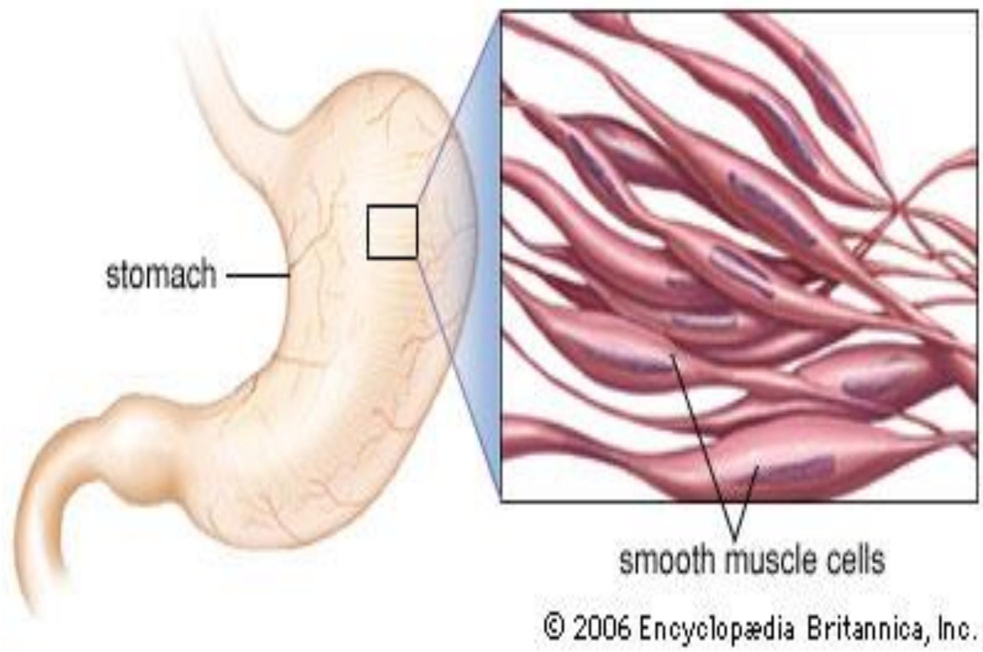

Figure 1.9 Smooth muscle [8]

Our stomach and small/large intestines do their muscular activities whole day but we never feel what's going on in there. They are long spindle shaped contractile cells. They show slow, weak and sustained contraction.

1.4.3 Cardiac Muscles

Cardiac muscles are also an "involuntary muscles" like smooth muscles but more similar in structure to skeletal muscles. These are found only in the heart of human body. The primary functions of the cardiac muscles are to contract and release. Endurance and consistency are the two main features, which make them unique from other muscle types. Its stretching is like smooth muscle but contraction like skeletal muscle. These muscles never get tired but continuously work without any rest. During contraction phase, blood is squeezed out of the heart, and fill it, when relaxed.

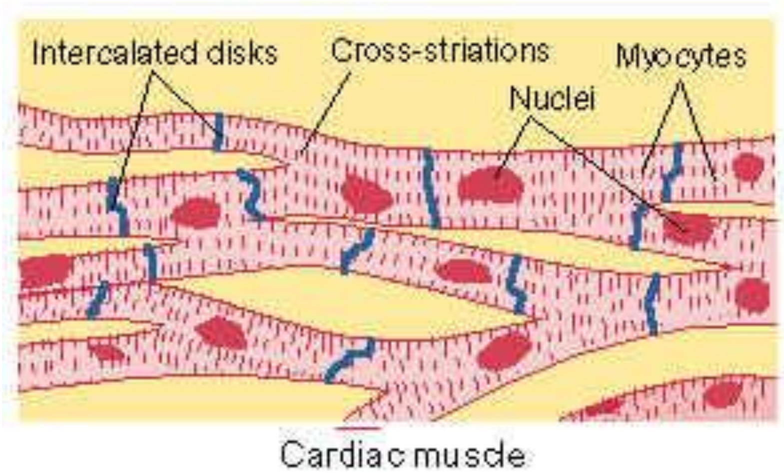

Figure 1.10 Cardiac muscle [9]

1.5 Action Potential (AP)

An electrical impulse generated due to movement of ions and resultantly contraction of muscle occurred in human body and such signal is called myoelectric signal. This term is used as regard to skeletal muscles that control movements of human body. Each skeletal muscle comprises several fiber cells. Fiber cells length is from few millimeters to about 30 centimeters and diameter range is from 10 to 100 micrometers. Each muscle fiber is filled with myofibrils which are filled with protein filaments. These are arranged in a highly ordered manner. Nerve's message is transmitted through motor neuron from the brain and causes these proteins filaments to interact and resultantly muscle contracts. Usually, the muscle length will be reduced to about 57% of their resting length, when muscle contract. This may further reduced up to 70% of the resting length if more strong signals received. When a cell is given voltage stimulus to its cell membrane that causes it to be less negative inside. When a negative voltage crosses beyond a threshold, the Na_+ channels swing open, allowing Na_+ to rush into the cell. As this process continues, it causes the inside of the cell to be more positively charged than the outside. The cell thus comes to net positive potential with respect to interstitial medium and is said to be *depolarized*. When this situation occurs, the K_+ gate opens, causing K_+ ions to rush outside the cell. The cell starts to be more negative inside again. Ultimately all of the gates close again, and the Na/K pump acts to restore the cell membrane to its negative voltage inside with respect to the outside. This transformation of cell from positive to negative again is called repolarization [5] and is shown in Figure 1.11.

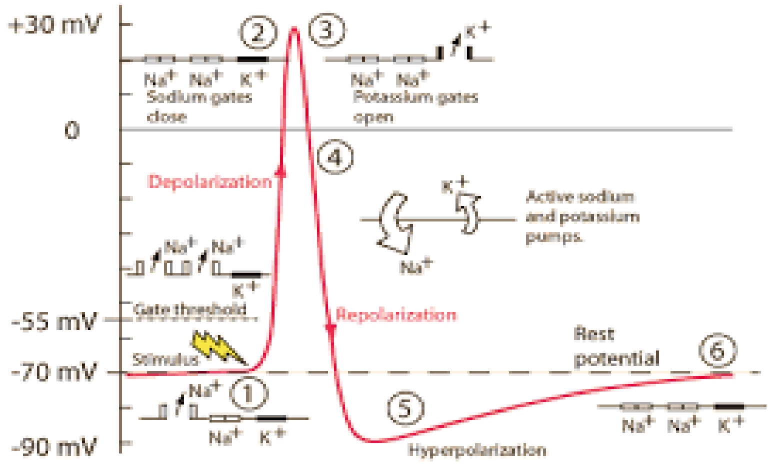

Figure 1.11 Action potential [10]

The entire process of depolarization and repolarization may take 1 millisecond in case of the nerve cell and approximately 300 milliseconds in case of a heart muscle. The change in voltage across the cell membrane during this time is termed as action potential. The specific characteristic of the action potential depends upon the type of muscle or nerve fibre that is being stimulated.

1.6 Characteristics of EMG signal

Electromyographic (EMG) activity is mainly the generation of biopotential signal due to muscle action. These signals are contaminated with multiple noise sources such as ambient noise due to power line, motion artifacts due to wire/electrode movement, movement artifacts and inherent instability of signal due to quasi-random nature of signal [6, 7]. It is entrenched fact that the amplitude of the EMG signal is random in nature. The strength of these signals is very weak and normally amplitude of these signals ranging 1-10 mV [6]. Generally, the bandwidth of these signals is from 0-500 Hz [8] and amplitude of signal is significant between 50-150 Hz [6]. 50 Hz radiation generated from power sources are the major cause of ambient noise [6]. The amplitude of ambient noise signal may be increased thrice than the EMG signal. Frequency range of motion artifacts/ inherent instability of EMG signal ranging 0-20 Hz [6,7]. Behavior of the amplitude of the EMG signal is quasi-random. Firing rate of motor units is also quasi-random in the frequency range of 0-20 Hz, making frequency components unstable in this region and causes unwanted noise [6]. Spectrum of raw EMG signal is shown as in figure 1.12 and its usable frequency spectrum as shown in figure 1.13 is presented below.

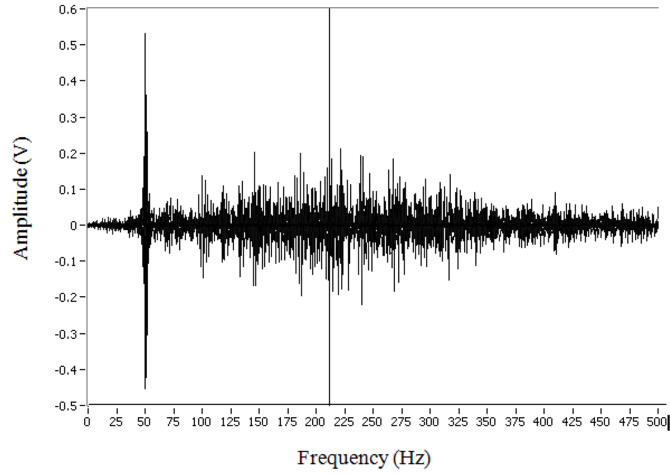

Figure 1.12 Spectrum of raw EMG signal

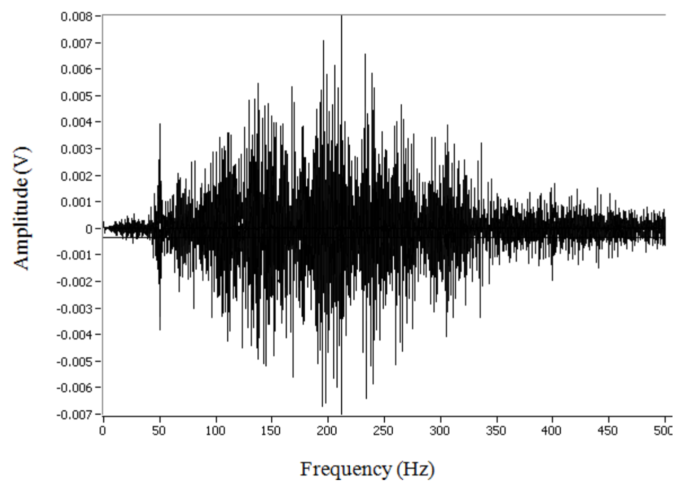

Figure 1.13 Useable Frequency spectrum of EMG signal

1.7 Electrodes

Electrodes are special devices that convert ionic potential into electronic potentials. These are the metal surface of the sensor which develops electrical contact with the skin. The electrodes used in electromyography, are of a wide variety basing on types and construction. While choosing electrode, it should be kept in mind that electrode be harmless and brought closer to the muscle to pick up the current generated because of ionic movement. Detection surface of electrode plays important role while acquiring EMG signal from muscle.

1.7.1 Types of Electrodes

Two kinds of electrodes are being used depending upon the requirement of user for acquiring/recording EMG signals [9].

- Inserting EMG Electrode
- Surface EMG Electrode

1.7.1.1 Inserting EMG Electrode

Needle electrode is inserted in the muscle under the supervision of trained professional for intramuscular EMG [3]. As needle electrode presents a highly localized picture of its activity, so the needle is retracted by few millimeters and recording of EMG signal is carried out [9]. Intramuscular EMG is performed only, when activity of specific fiber of muscle is required to be studied in detail otherwise SEMG electrodes are suffice for study of the activity of group of muscle to avoid piercing of skin.

1.7.1.2 Needle Electrode

Needle electrodes are further classified into two types [9] i.e; the concentric and monopolar needles. The design of these two most popular types of EMG needle electrodes remains almost unchanged since their introduction in the forties. However both design present different characteristics. Nowadays, most monopolar needles are made of stainless steel with a gauge ranging from 26 to 31. The needle is covered with an insulating material layer normally with an acrylic coating. Moreover, the needle is covered with a second layer of medical silicone aiming to decrease the friction between the needle and the biological tissue, facilitating the penetration and decreasing the discomfort of the patient.

The most critical factors in the recording of EMG signal is the conducting area of tip as it is directly related to the pick-up field and the amplitude of the recorded activity. The EMG measurement is performed by inserting the monopolar needle (active electrode) as close as possible to the area of interest. The reference electrode, generally a surface electrode, is placed close to the active electrode but not on the active tissue. Finally, a ground electrode is placed relatively away from these two electrodes.

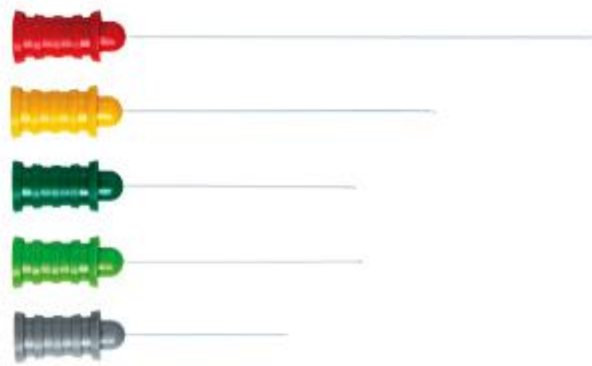

Figure1.14 Monoploar needle electrode [11]

The concentric needle consists of a cannula and a core. Cannula is taken as reference electrode and a core as active electrode. Both are made of different materials. The outer diameter of the cannula is generally 0.45 to 0.7 mm diameter and the core approximately 0.1 mm diameter. The core is embedded in an insulating material, due to which both electrodes are electrically insulated. The shape of the tip of the needle is flat elliptical and is grounded to an angle, which is roughly of 15 degrees. Concentric needle has a core of silver and a cannula of stainless steel. The monopolar needles record activity from all directions, however, concentric needles record mainly signals in the direction of the elliptical surface (bevel) and must be rotated to pickup activity from fibers in other directions. Resultantly monopolar needles then record more electrical activity than do concentric needles.

Needle electrode is a kind of inserting electrode. This looks like a cannula and inserted in the body for recording the required signal. The signal obtained from this kind of electrodes has a good signal quality as well as strength [9]. One of the major benefits of Needle electrodes is its small pickup area. It helps to detect individual MUAPs during relatively low force contractions [9]. The other is that exploration of new tissue territories may be possible due to conveniently repositioning of electrode within the muscle (after insertion).

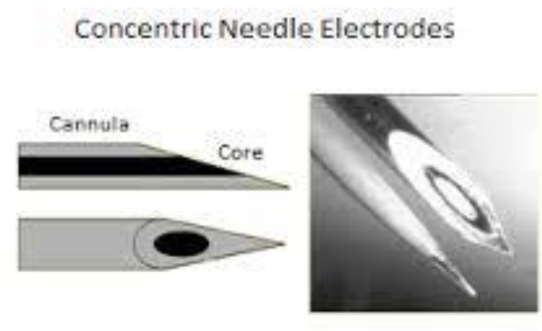

Figure1.15 Concentric needle electrode [12]

1.7.1.3 Fine Wire Electrode

Wire electrode is an inserting type of electrode. Wire electrodes are very thin and made of alloys of platinum and silver. They are less painful for patient as compared to other electrodes. It is easy to insert or remove fine wire electrode from body [9].

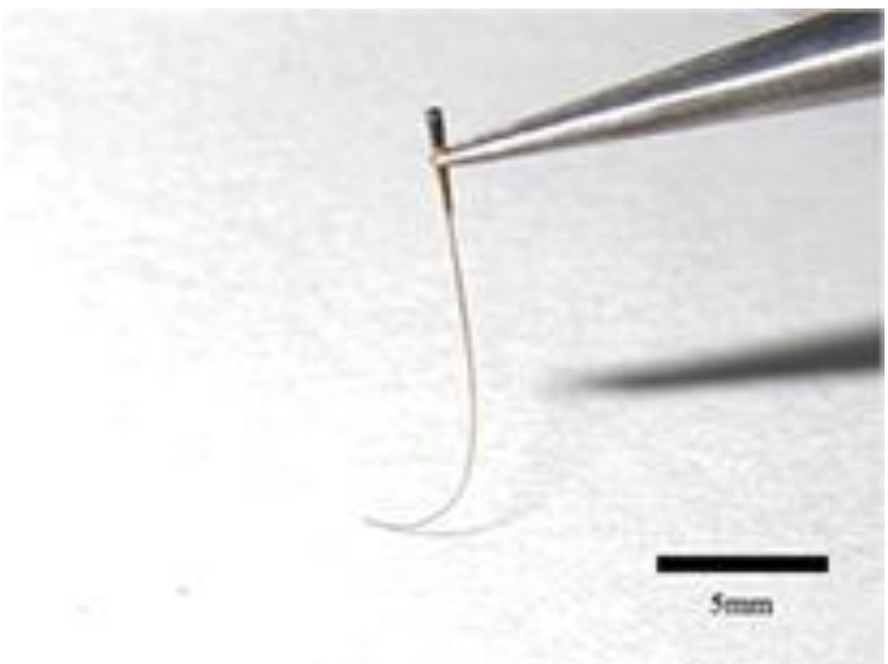

Figure1.16 Fine wire electrode [13]

1.7.2 Surface Electrode

Surface EMG electrodes are used where a non-invasive system for detecting EMG signal is required. They provide limited assessment of muscle activity. Handling and usage of these electrodes is very easy. Surface EMG electrodes are used in a number of places in medical. They are used to detect the neuron signal and further send the signal to control device to take action accordingly. At their earliest, immersion electrodes, which were simply buckets of saline solution into which the subject placed his hand and feet were used for measurement of biopotential signal. With the advancement in electromyography field, plate electrodes were introduced. These electrodes were separated from the subject's skin by cotton or felt pads soaked in a strong saline solution. Later on, a paste or conductive jelly replaced the soaked pads. Common problems with these electrodes were suffered from movement. Even the slightest movement changes the thickness of the thin film of electrolyte between metal and skin. To eliminate this movement problem, floating electrodes were introduced by avoiding any direct contact of metal with the skin. Presently, disposable electrodes have been introduced to eliminate the requirement of cleaning and care after each use. These are cheap, small in size and require no maintenance.

Surface EMG electrode has a problem associated with them as these muscles have to mount on skin so these electrodes cannot be used at the places where skin position with respect to electrode can't remain stable. If it happens then electrode was unable to pick the actual signal and useful information will be lost. Two different types of skin surface electrodes are shown below in Figure 1.17.

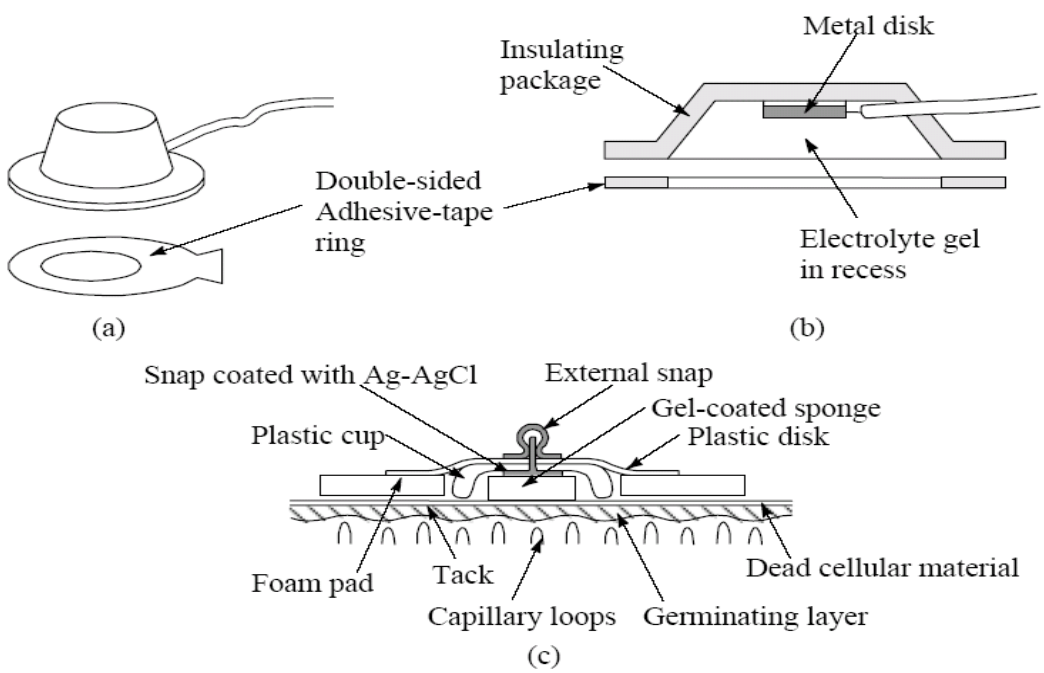

Figure 1.17: a) Floating electrode, b) Cross-sectional view, c) Disposable Electrode [14]

Dry EMG electrodes neither require a gel interface for adhesion or to increase the conduction nor any special requirement of skin preparation. These electrodes may have more than one point for detection of signals. Motion artifact level for dry electrodes is lower than wet electrodes [10]. Dry electrodes are generally heavier than other surface electrodes. Due to increased weight, they often encounter problems in fixing them. To stick them to human body, normally suction technique is used.

Figure1.18 Dry EMG electrode [15]

When a metal electrode gets in contact with a skin through a solution, it generates a local change in the concentration of the ions in solution near skin-electrode junction. Neutrality of charge is disturbed at this junction. Due to this, electrical potential is varied from rest of the solution. Hence a potential difference known as half-cell potential, is established between the bulk of the electrolyte and metal. It is revealed that half cell potential varies metal to metal basing on their chemical characteristics. Half cell potential of few metals is summarized in Table 1-1 [11].

Table 1-1 Half-cell Potentials for different metals

Metal and Reaction	Half-cell Potential, V
$Al \rightarrow Al^{3+} + 3e^-$	–1.706
$Ni \rightarrow Ni^{2+} + 2e^-$	–0.230
$H_2 \rightarrow 2H^+ + 2e^-$	0.000 (by definition)
$Ag + Cl^- \rightarrow AgCl + e^-$	+0.223
$Ag \rightarrow Ag^+ + e^-$	+0.799
$Au \rightarrow Au^+ + e^-$	+1.680

1.7.2.1 Gelled Surface Electrode

Another type of surface electrode is gelled surface electrode. It uses a gel for adhesion purpose and to increase the conduction of EMG signal from body to electrode and also to reduce the skin impedance. Ag-AgCl is the most commonly used composite material being used for gelled electrodes. Current travels freely because of AgCl layer from the junction point. Because of this reason, less electrical error in measurement will be observed as compared to other metallic electrodes. Due to this reality, Ag-AgCl electrodes are being used in more than 80% of surface EMG applications [12]. EMG electrodes are mostly used as a disposable electrode. For the best detection of the signal, proper skin preparation is required before application of gel.

Figure1.19 Gelled EMG electrode [16]

1.8 Advantages of EMG

- Directly observe the subject muscle.
- It helps to ascertain the muscular performance of human body.
- It is very beneficial in decision making when surgery of patient is planned.
- It helps in training regimes and beneficial in documents treatment.
- It helps patients to evaluate and train their muscles.
- Helps to improve upon sports activities of sports man.
- It helps to detect muscle response in ergonomic studies.

1.9 Multidimensional Usage of EMG

Usage of EMG signals in several applications like clinical or biomedical applications, human machine interaction, rehabilitation and sports is evident [13]. Besides biomechanical and basic physiological studies, EMG is recognized as an assessment tool for applied research, rehabilitation, sports man training and interactions of the human body to industrial products and ergonomics [13]. EMG as a diagnostics tool being used in many clinical applications such as neuromuscular and neurological diseases, low back pain assessment, kinesiology and disorders of motor control, posture analysis [14]. Rehabilitation of a muscle is mandatory after post-surgery or accident. It is also used in Gait analysis of subject under test. EMG signal analysis helps in neurological rehabilitation. It is helpful in preparation of active training therapy and physical therapy of a muscle for a particular patient. EMG also helps in sports science. Most important use of EMG signal is control of prosthetic limb. It is helpful in preparing athletes strength training and sports rehabilitation after any injury. Gait laboratories are using EMG as diagnostic tool and by clinicians trained in the use of ergonomic assessment. Raisy C D et al; [15] worked on real time EMG acquisition and recognition of head movement. Similarly Maged S. Al-Quraishi et al; [16] used SEMG signal to analyze ankle joint movement.

1.10 Interim Conclusion

In this chapter, importance of muscles was discussed. Their role in human body and its functionality was discussed. Functioning of cell is discussed, which is the main constituents of electromyogram. The biopotential signals from muscles help to diagnose the nerve disease. These signals are generated from the cells of the muscles, when they are stimulated by nerve cells. Myoelectric signal is an electrical impulse which produces contraction of muscle fibers in human body. The electromyogram (EMG) is basically a superimposed signal generated from all of the MUAPs in a detected area. To pick up these signals different types of electrodes are used which are explained above. At last applications of EMG were discussed.

CHAPTER 2: LITERATURE REVIEW

Literature review is a prime part of research work. It is proven to be a beacon and leading us to achieve our set objectives. It also provides us a path to true analysis of previous work, make us worthy to understand the problem. This chapter deals with the research work carried out by different authors in the field of Electromyography, which is the study of muscle function through the inquiry of the electrical signal the muscles emanate [13]. SEMG signal acquisition and signal conditioning is a trivial job. In recent years, due to major advancement in the field of electronics, helps researchers to attain higher standard of EMG signal acquisition and better design of signal conditioning circuits through research of different parameters that affects the quality of EMG signal. In this chapter, multi research parameters of electromyography, discussed by different researchers are briefly discussed.

Carlo J. De Luca [1] described that EMG signal that originates in the muscle due to motor neuron is contaminated by various noise sources. Resultantly wrong interpretation of EMG signal is carried out. There are multi intrinsic and extrinsic noise sources that can be eliminated with the help of modern technology and better circuit design. In this study, more focus was on removal of motion artifacts due to muscle contraction at skin-electrode interface. Acquired EMG data was filtered at high pass corner frequencies (1, 10, 20, 30) Hz at slope rate of 12dB/octave and 24dB/octave. The effect of slope rate was not significant so 12dB/octave slope is discussed. Through experiments, author revealed that power spectral density lies mostly between 20 to 200 Hz. The effect of high pass corner frequency on the base line noise and movement artifact signals was higher as compared to EMG signal. Linear decrease in amplitude response is observed in case of EMG signal where as non-linear response is observed in case of baseline noise and the movement artifact signals, when corner frequency is taken into account. By evaluating the response of different corner frequencies on reduction of EMG signal, 20 Hz is found the most suitable choice.

Jingpeng Wang et al. [4] presented a design of an EMG signal conditioning and its amplification using an instrumentation amplifier. High/ low pass active filters with Sallen-Key topology were used. 2^{nd} and 4^{th} order filters are utilized in the proposed circuit and experimental results verified the effect of 2^{nd} and 4^{th} order high pass filter is same at lower frequency. 2^{nd} order filter had a roll off of -12dB/Octave and corner frequency was 20 Hz, whereas 4^{th} order filter had a roll off of -24dB/Octave but same corner frequency. Different sampling rates i.e; 500 Hz, 1000 Hz, 1024 Hz, 2000 Hz and 4000 Hz are evaluated to convert analog-to-digital conversion of EMG signals without aliasing effects. Even 4^{th} order low pass filter could not remove aliasing while using sampling rate of 1000 Hz as per Nyquist Shannon theorem to convert analog to digital conversion. Finally sampling rate of 2000 Hz is suggested to detect EMG signal. The authors verified through experiments that 2000 Hz sampling rate was higher enough to attenuate the frequencies above 500 Hz.

Pascal Laferriere et al. [5] described that EMG signals are electrical signals which are generated due to muscle contractions. These signals are acquired by using different electrodes and are used in multiple applications as diagnostic tool. Wet electrodes such as Ag/AgCl electrodes present better quality signal but proven to be ineffective if used for prolonged period as gel may be dried. Special skin preparation is required if wet electrodes are to be used. Due to skin preparation, impedance of skin-electrode junction will be reduced. For long term monitoring, we require dry electrodes, which don’t require special skin preparation, application of gel and expertise of acquiring signal acquisition. In this study, different dry electrodes are compared against a conventional pregelled Ag/AgCl electrode.

Carlo J. De Luca [6] discussed the characteristics of EMG signal and characteristics of electrical noise sources. Differential amplification technique is used to eliminate power line noises. The signal is detected at two sites and differential amplifier would subtract the common signals, detected at both sites but would only amplify the difference. CMRR is basically the main parameter, which dictate the accuracy of differential amplifier subtraction. Generally CMRR of 90 dB is sufficient to effectively suppress the extraneous electrical noises. High input impedance is mandatory to eliminate the effects of input loading. Moreover active electrode design is recommended to avoid capacitance coupling at the input of differential amplifier. SNR of signal can be enhanced by judiciously filtering of EMG signal between 20-500 Hz with roll off of 12 dB/octave. Electrode geometry is discussed and inter-electrode spacing 1 cm is suggested as this space is high enough to avoid shortening of path even when skin is wet. Electrode of pure silver (>99.5%) having dimension (1cm length and 1mm dia) is found to be sufficiently good material for detecting surface. EMG electrode placement is discussed RMS value is preferred for signal processing as RMS measure the power of signal.

M.B.I. Raez et al. [7] mentioned in their work that EMG signal is dependent on the anatomical and physiological properties of muscles. It is a complex signal, which is controlled by the nervous system of human body. Shapes and firing rates of Motor Unit Action Potentials in EMG signals are the key factors in diagnosis of neuromuscular disorders. Recent advancement in the field of signal processing and mathematical models has made it feasible to develop advanced EMG detection and analysis techniques. Various mathematical techniques and Artificial Intelligence (AI) have received extensive attraction. Different Mathematical models were discussed in this study. Three methods are discussed for detection of EMG signal based on threshold method. Decomposition of EMG signal is suggested to reveal the mechanisms pertaining to muscle and nerve control.

Carlo De Luca [9] discussed different factors such as causative, intermediate and deterministic. EMG signal generation till acquisition and its filtering in his study. EMG signal's characteristics are elaborated. Invasive and non-invasive techniques and their benefits are discussed. Different signal analysis techniques such as average rectified signal, integration, RMS, frequency domain analysis and zero crossings and turn counting are discussed.

Yu Mike Chi et al. [10] had explored the usage of dry electrodes coupled with noncontact electrodes for clinical use. As usage of conventional wet adhesive Ag/AgCl electrodes are cumbersome for prolonged and mobile usage. They discussed skin-electrode junction impedance of various gel free electrodes such as dry, insulated and non-contacts electrodes also discussed the methodologies to reduce the skin impedance.

Authors recommended a modern FET-input amplifier having unity-gain is considered most suitable buffer to buffer signals from virtually any electrode. Due to advancement in this field, achieving sufficiently high input impedance is not a problem. Input offsets are troublesome. However DC-coupled instrumentation with very low gains and high-resolution ADCs can tolerate large electrode offsets.

A Searle and L Kirkup [12] described comparison among three types of bio-electrodes on quantitative basis. These electrodes include wet, dry and insulating type. Different parameters such as impedance of electrode, static interference and motion artifact induced by different means, are considered during comparison test performed. Physical environment was same for all three electrodes. The performance of dry and insulating electrodes both found favorably as compared to wet electrodes. The effect of non-stationary electric fields on shielded dry and insulating electrode types was observed and compared it with wet types. Interference of dry and insulating electrode types was 40 dB and 34 dB less than that of wet electrode. At the beginning of trials, artifact levels for dry and insulating electrodes were significantly higher than those for wet types. However at the end of the trial periods, artifact levels for dry and insulating types were lower than wet electrodes by an average of 8.2 dB and 6.8 dB respectively.

Peter Konrad [13] wrote a short teaching manual about electromyography. In his manual, wide spread use of EMG particularly in medical research, rehabilitation, ergonomics and sports science is discussed. Complete detail of EMG signal generation due to excitability of muscle membrane till acquisition and signal conditioning and measurement is discussed. Different measurement methods are also discussed.

Raisy C D et al. [15] presented their work on real time EMG acquisition and recognition of head movement. A simple and cost effective method is used for evaluating human head movements from neck EMG signals. They had acquired surface EMG signal from four main neck muscles by using simple computer interface and to acquire noise free signal, MATLAB based filter algorithm was used.

Maged S. Al-Quraishi et al. [16] presented their work about acquiring the EMG signal while ankle joint movements are performed. Four channels are used to acquire EMG signal. Acquired signal sampling rate was 2 kHz. Labview software is used for displaying and storing the acquired signal. Mean absolute value analysis algorithm is used for EMG temporal representation and investigation of muscles activity level.

Rubana H. Chowdhury et al. [17] had reviewed two major areas; one is pre-processing method to eliminate unwanted noises at the start of signal acquisition and second is a brief explanation of the different methods for processing and classifying EMG signals. Number of methods for analyzing EMG signals is discussed basing on their performance. The crux of this paper is to review the most recent developments and research studies related to the issues of analyzing EMG signals. Authors discussed recent advances in the field of EMG signal processing. The main advantage of using a wavelet basic function is due to its continuous derivatives, which warrants it to decompose a continuous function more efficiently. It also avoids unwanted signals. Authors evaluated that Daubechies's wavelet is proven to be better energy concentration with long-length filters than those with short-length filters. For obtaining better results from a SEMG analysis on different applications, the authors recommend to use the db function at decomposition level 4. EMG feature extraction and classifier techniques and their comparison are discussed in this study.

A.N. Norali et al. [18] reviewed the works on clinical application and engineering research such as prosthetic arm and speech recognition. Different signal conditioning techniques to remove noises from SEMG signal, adopted by different researchers have been discussed. For signal measurement, root mean square and mean absolute value are recommended. RMS is square root of average power of a signal for given period of time. MAV on the other hand is area under the signal. RMS is usually preferred than MAV. Through frequency spectrum, measurement of the signal is being evaluated by parameters like power spectral density (PSD), mean frequency and median frequency.

Carlo J. DeLuca et al. [19] evaluated the influence of inter-electrode spacing on using bar and disk electrode arrays. Its effect is evaluated on degree of crosstalk contamination. 5 mm to 40 mm inter-electrode spacing is used to acquire single-differential signals. Minimum crosstalk contamination was observed when inter-electrode space was selected 10 mm. No significant differences between the bar and disk electrode arrays were observed during experimentation stage. If electrode spacing is enhanced from 10mm then cross talk contamination will be increased and if spacing is reduced from 10mm to 5mm then again percentage of contamination will be increased but due to dominance of base line noise components.

In his article, Dr. Scott Day [21] discussed that EMG signal is generated due to movement of ions across muscle fiber cell membrane. The amplitude of signal is dependent on strength of muscle contraction, placement of electrode and its distance from active muscle, properties of muscle tissues, amplifier design, electrode properties and quality of skin-electrode contact. Ambient noise (50 Hz frequency) is one of the sources of noise due to electromagnetic devices. DC voltage potential is generated due to impedance difference between the skin and the electrode sensor. Whereas AC voltage potential caused by fluctuation of impedance at skin electrode junction. Consistency in impedance is critical for the reliability of EMG measurements. However this factor may overcome by using very high input impedance of Instrumentation amplifier. If difference in impedance at both sites has been enhanced then signal strength entering in differential amplification will also be increased and resultantly ratio of noise components will also be enhanced.

To remove the effect of input loading, very high input impedance is recommended as compared to source impedance (impedance of skin) otherwise signal will be attenuated. Skin-electrode impedance for dry and wet electrode is discussed. Distance of signal source should be minimized to remove the effect of capacitive coupling.

HAKW. TAM and John G. Webster [22] represented in their work that motion artifacts are the major source of erroneous results in biopotential measurement. They had recommended in their work that conducting paste be used with electrodes to reduce motion artifact in skin potential. Light abrasion of the skin was found to be the most effective means of minimizing motion artifacts. Authors suggested that mild paste be used to avoid skin irritation. Skin potential of different body part is recorded and it also varied among different subjects.

Paulo Roberto Stefani Sanches et al. [24] presented the development of an innovative biomedical application. They used Field Programmable Analog Arrays (FPAAs) in their work. Single FPAA is used for conditioning of EMG signals. It was used to control external devices such as prostheses or electrical stimulators. To minimizing ripple and smoothing, they had recommended 1.5 Hz cut off frequency.

Yinfeng Fang et al. [25] proposed a 16-channel acquisition system. A novel SEMG electrodes array is used to capture forearm muscular activity. They employed elastic fabric to 18 dry electrodes. Due to this, reusability and wear ability is enhanced. Furthermore, a new graphic presentation of forearm SEMG signal is proposed in this study. Muscular activities can be witnessed in the form of round image patterns. From this pattern, even strength and location of muscle can be determined.

Jolantan Palk [26] used different techniques of EMG signal analysis in her study. Author used wavelet transform, filtering and modeling in this paper. By doing so, provides an efficient and effective ways of understanding the signal. A comparison study is carried out to evaluate the performance of various EMG signal analysis methods. Polynomial filter based on microprocessor is used for filtering electromyography signals. For local analysis of non-stationary and fast transient signal, wavelet transform (WT) was found to be an efficient mathematical tool. Regression model is used in this work to study the activity of muscle.

Wonkeun Youn and Jung Kim [27] developed, a compact size, wireless EMG measurement system. Bluetooth technology is incorporated in this study. The performance of the developed system was evaluated in comparison with it of a commercially available EMG measurement system, using SNR and power spectrum density (PSD). The developed EMG system consists of an preamplifier which measure and initially amplifies the EMG signal, a band-pass filter, a band reject filter, a DSP which performs A/D conversion and digital signal processing. SNR of EMG signal obtained by developed EMG is higher than it of the commercial EMG system.

Mohammed M. Shobaki et al. [28] described that SEMG signals are used as diagnostic tool for multidimensional applications. Acquisition quality of acsuch signals are influenced by different parameters such as inter electrode distance, position and configuration of electrodes.. Signal quality is determined by SNR. Effective signal conditioning leads to enhance signal quality and hence required better signal conditioning circuit.

Dimitrios Barbakos et al. [29] developed low cost sensor for EMG recording and the analysis of these signals. It assists the expert kinesiologists or clinicians' on decision making using simple features in a real-time manner. The model, which they had presented, used a SEMG signal acquisition facility from single differential channel. SEMG signal is acquired from the biceps brachii muscle, which may also be used in other surface body muscles.

Ananda Sankar Kundu et al. [31] designed single supply wearable EMG extractor unit for wireless EMG monitoring. Acquisition and processing of multichannel EMG signal is done by ATMEGA 8 processor. Data is transmitted to computer with c#.net platform for signal processing and visualization through RF module. AD623 Instrumentation amplifier is used due to single polarity supply. Ag/AgCl Biopotential disposable electrodes are used with 20mm inter-electrode distance. Preamplifier design is divided in 2 stages. Use of 11 and 101 in the respective stages makes a total gain of 1111. ATMEGA8 microcontroller is used for data acquisition. 10 bit, 6 channel A/D converter used with a sampling speed of 1 kHz. The sampled data is sent to the USART with a baud rate of 115200 bps. XBEE digimesh 2.4 OEM RF module is used for wireless transmission. It has been used in the system for indoor application up to 30metre range.

A Melaku et al. [33] studied the effect of inter-electrode distance on the amplitude of SEMG. EMG signal was recorded by surface electrodes having inter electrode distance between the two active electrodes being 18 and 36mm. During experiment, they have observed that there was no significant variation due to the change in the distance between the electrodes at low levels of muscle contraction while significant change in the amplitude of the EMG is observed at 50 and 80% of MVC.

Suraj R. Gaikwad and Gopal S. Gawande [35] described that in practical applications of digital signal processing, there is requirement of processing the multiple signals at different sampling rate with corresponding bandwidth of the signals. System used for such sampling rate conversion is called multirate digital signal processing system. Multirate filters are used to reduce the processing cost. However in decimation, the sampling rate is reduced by factor M and it discarded $M - 1$ samples for every M samples in the original sequence. Fs is sampling frequency and M is factor by which sampling rate is reduced. Before decimation, an anti-aliasing digital filter be used to prevent aliasing from occurring, due to the lower sampling rate. In this paper, Simulink model for three stage decimation filter using Xilinx System Generator, used for the audio application. Very high input signal rate having frequency 1.28 MHz is decimated at about 4 KHz. 4 Stage CIC filter having decimation factor 16, is used. Thus it changed the signal rate to 80 KHz. The drawback of a CIC filter is that its pass band is not flat. Two FIR-FIR filters are used which warrants great control over filter shaping and linear phase performance. Advantage of three stage decimation filter has less power consumption due to the usage of Multiplierless CIC filter.

CHAPTER 3: SURFACE ELECTROMYOGRAPHY (SEMG)

Electromyographic (EMG) activity is basically generation of biopotential signal because of muscle action. These EMG signals can be acquired by both invasive and non-invasive way. While using invasive technique, we use needle electrodes where as in non-invasive technique, dry/wet electrodes are used. As electrodes are used on the surface of skin, it is called as surface electromyography (SEMG). It is a universal technique, used for acquiring the signals from muscle. Surface electromyography (SEMG) can be defined as a non-invasive method of acquiring electrical activity of muscle when muscle contracts.

3.1 Factors Affecting on Acquiring SEMG Signal

Response of SEMG signal is affected by multiple factors such as:-

- Type of muscle tissue.
- Use of muscle.
- Diameter of muscle fiber.
- Number of muscle fibers per bundle.
- Degree of individual development.
- Degree of fatigue present.
- Multiple noise sources.
- Depth of muscle.
- Spacing of electrodes.
- Effect of neighboring muscle.

3.1.1 Multiple Noise Sources

As far as recording of SEMG signal is concerned, fidelity of the signal is influenced by many factors. Fidelity of signal is ascertained through Signal-to-Noise Ratio (SNR). It is the ratio of the power present in the EMG signals to the power of noise present in signal and is generally expressed in decibles (dB). The basic goal in EMG measurement is higher SNR.

$$SNR = P_{signal}/P_{Noise} \tag{3.1}$$

In broader way, noise is an unwanted signal which coupled with actual EMG signal. The noise may come from various sources which are described in succeeding paragraphs.

3.1.1.1 Inherent Noise

Electronic components used in the detection and conditioning of signal are the main source of this noise. All electronics equipment being used in our surrounding generates electrical noise. The frequency range of such noise is from 0 Hz to several thousand Hz [6,17]. Using superior quality electronic components , this noise can be reduced.

3.1.1.2 Ambient Noise

Electromagnetic radiation due to power line is the main source. Generally radio, television, electrical-power wires, light bulbs, fluorescent lamps and multiple electrical appliances are the main sources [6]. Our own bodies are constantly flooded with electric-magnetic radiation and practically impossible to avoid this exposure on the surface of the earth. The significant concern for the ambient noise arises from the 60 Hz (or 50 Hz) radiation from power sources [18]. The ambient noise signal may have amplitude thrice of magnitude greater than the EMG signal [6].

3.1.1.3 Motion Artifacts

Motion artifacts are another source of electrical noise. In SEMG signal acquisition, skin-electrode junction is one of the source of motion artifacts where as movement of cable connecting the electrode to amplifier is another source of motion artifacts [6,15]. Both of these sources can be minimized by using active electrode where wire connections are eliminated from electrode to instrumentation amplifier [19]. Frequency range of this noise source is ranging from 0 to 20 Hz.

3.1.1.4 Inherent Instability of the Signal

The amplitude of the EMG signal is not smooth like other electrical signals but quasi-random in nature. Due to this nature of the firing rate of the motor units, frequency components of SEMG signals ranging from 0 and 20 Hz are particularly unstable. Because of this unstable behavior, this range of signal be considered as unwanted noise and remove them from the signal by using high pass filter [6, 15].

3.1.2 Depth of the Muscle

It is an important variable. Figure 3.1 shows two muscles but lie at different depth under the skin. Both are almost equally active as indicated by the length of vectors inside the muscle. So the amount of conducting medium lying between the skin and muscle is different in both the cases [20]. Actually, the conducting medium acts as a partial short circuit to the electrical output of the muscle. Hence the surface electrode over deeper muscle would pick up less electrical activity as compared to one which is just located over the muscle which is just beneath the skin surface [20]. On the other hand, we can say that electrical activity is inversely proportion to the depth of muscle.

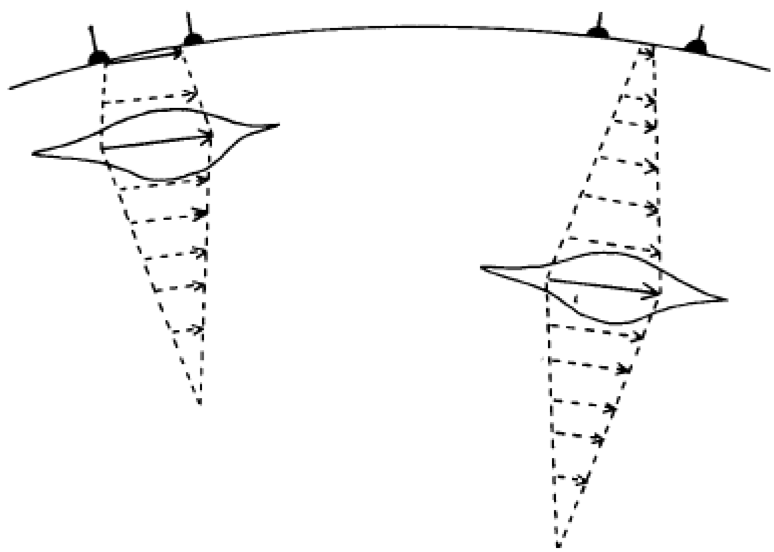

Figure 3.1 Surface activity and Depth of muscle

3.1.3 Spacing of Electrode

Spacing of electrode on the surface over a muscle is another important variable, which plays important role to measure the exact performance of any muscle. If same factor is not given due weight-age during signal acquisition, then resultantly neighboring muscles will also start contributing in electrical activity and as a result exact performance of muscle will not be judged [20].

In figure 3.2, the little vectors just under the skin are shown, which represent the amount of electrical potential reaching the skin and same do not appear only at one small point. They appear in varying degree all over the skin nearby but electrical potential is largest immediately over the muscle involved. Figure 3.2 shows the three electrodes, which are placed immediately over a muscle. If inter-electrode spacing is equal then the pair of electrode AB and the pair BC are of similar spacing [20]. If these pair of electrodes is symmetrically placed over the muscle, then we can expect to get about the same amount of electrical activity from each pair.

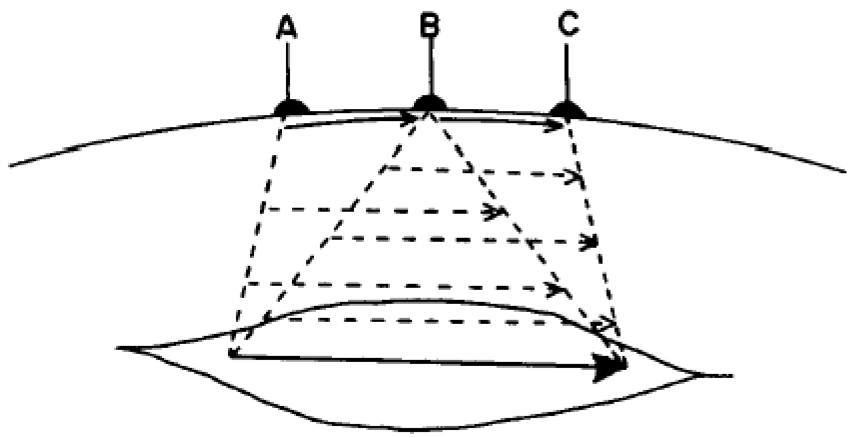

Figure 3.2 Effect of electrode spacing

Now if we look into figure 3.2 and taken into account pair of electrodes AC, we are basically adding electrically the two small vectors AB and BC. Resultantly, we would expect to get about twice as much electrical activity from this pair AC as compared to AB and BC. But it is not so simple case, there must be some rational between electrode spacing as more electrode spacing would result cross talk of muscles. De Luca suggested in his study that 10mm electrode spacing is preferred to reduce cross talk. [19].If electrode spacing is enhanced from 10mm then cross talk contamination will be increased and if spacing is reduced from 10mm to 5mm then again percentage of contamination will be enhanced but due to dominance of base line noise components [19].

3.1.4 Separation of Activity

Separation of activity from neighboring muscles is probably best accomplished with electrodes spaced closed together over the desired muscle. Two muscles with equal activity at different depths as shown in Figure 3.3 are under consideration. We can witness how the neighboring muscle signal will be picked up by electrodes of different spacing.

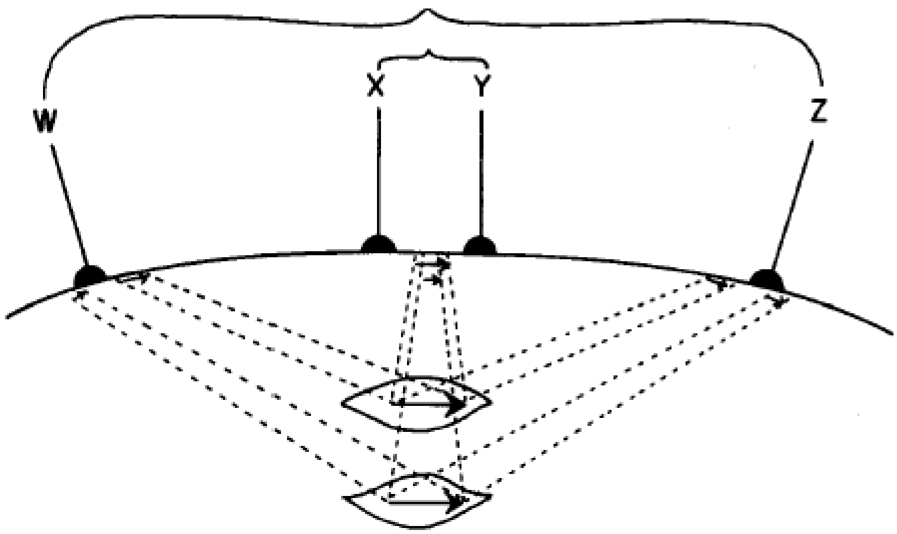

Figure 3.3 Differentiation of muscles at varying depths

If we consider narrowing spaced electrodes, then we will get a certain SNR of desired to undesired signals from the two muscles. As the spacing is increased, both the desired and undesired signals increase yet SNR remains constant for a time and there is no gain or loss in differentiation. However if inter-electrode distance approaches and exceeds the physical size of the desired muscle, then the desired signal no longer increases in proportion to the increasing electrode spacing [20]. On the other hand, the signal from the undesired muscle may, at the same time, continue to increase in proportion to the spacing since the surface electrical field from this deeper muscle may be more uniform. We can say that SNR has been reduced. Again from the figure, XY electrodes evidently would discriminate against the signals from the deeper muscles better than the WZ electrodes [20].

3.2 The Significance of Skin – Electrode Impedance

Skin-Electrode impedance is very vital for the reliability of EMG measurements, as same is not observed equal at both measurement sites. Moreover this impedance is reduced with passage of time but decaying at exponential rate, which leads to a settling point within a short amount of time from 10 mins to even 30 mins [5]. Stability in impedance over time has a considerable effect on the signal to noise ratio (SNR) of the measured EMG signal. Moreover balance in impedance between electrode sites also effect on signal to noise ratio. To reduce noise components, the balance in impedance between electrode sites for SEMG signal acquisition is important [21]. The impedance at each SEMG signal measuring site cannot be perfectly equal however same should be relatively similar. As the impedance between electrode sites varies, then following effects will occur:-

- Differential amplified signal strength would be higher.
- Differential amplification technique is used to cancel out common signal components. However in general, energy of power-line noise would be different at both sites then some of the noise will remain be coupled with actual signal, and will form part of differential amplification.
- Practically D/C voltage potential will also be found different at both sites and part of it will not be cancelled. Absence of sufficient D/C noise suppression in the residual D/C component, may lead to pre-amplifier instability, inaccuracy and saturation of op amp.

To minimize above effects, skin- electrode impedance between electrode sites should be more balanced and resultantly will get higher the signal to noise ratio (SNR). Moreover be ensured before start reading of SEMG signal that impedance has been stable. The skin potential varies greatly among subjects. Even when using the same subject, the same sites, and the same amount of time for electrode stabilization, the skin potential differed by ± 10 mV at different trials [22].

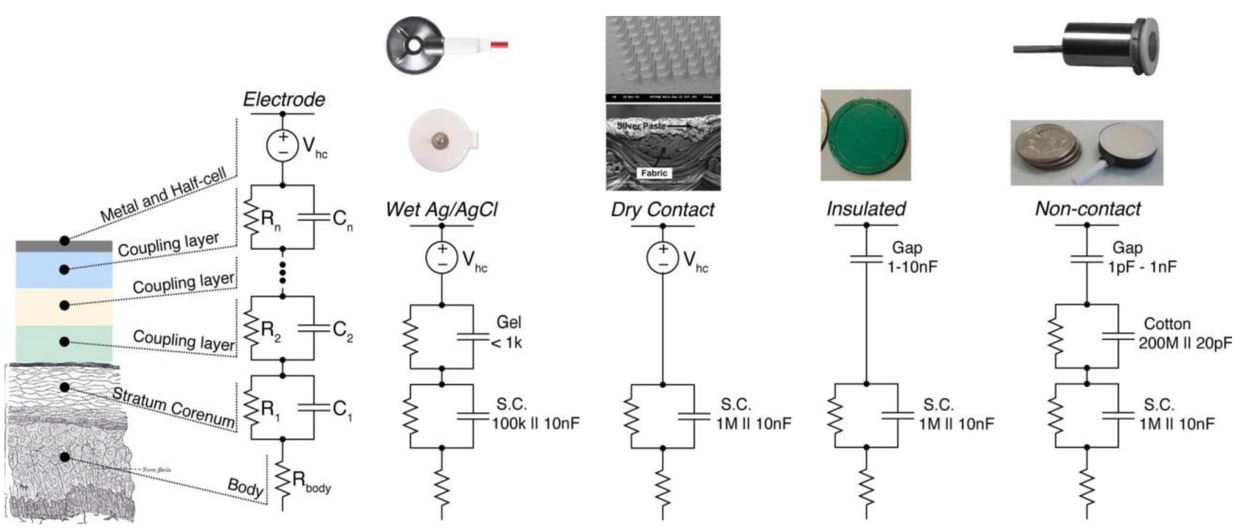

Figure 3.4 Skin-electrode impedance against different surface electrodes

3.3 Advantages and Disadvantages of SEMG

The use of SEMG signal has many advantages:

- Quantification of the energy of the muscle becomes simple because of SEMG as it proven to be a safe and easiest method for quantification.
- Since SEMG is a non-invasive technique, therefore it is painless method to acquiresignal from single motor unit to get useful and meaningful information regarding muscles.
- This technique allows the observer to observe the muscle energy response at rest and at fatigue as well.
- Different aspects of muscle are analyzed because of multiple sensor arrays.
- Numerical printouts and signal tracings associated with SEMG are the main source of information to clinicians and researchers regarding mechanisms of muscle function and dysfunction.
- The biological information obtained through SEMG methods can be feedback to the patient, providing the basis for neuromuscular re-education and for self-regulation. Such information helpful in fine tuning of the response of the patient's nervous system to the therapist's verbal instructions.

Disadvantages of SEMG are:

- Only limited muscle sites can be monitored but we are unable to get any useful information regarding deeper muscles inside the human body.
- For evocative and practical information about any muscle, bare minimum requirement of four channel SEMG instrument is needed which allows us to study the right and left aspect of two opposing groups but single channel of SEMG information is very limited.
- Major concern with SEMG is the possibility of crosstalk. Due to this phenomenon, signal from one muscle group travels over into the recording field of another muscle group and resultantly we cannot judge the actual performance of muscle.

3.4 Categories of surface electrode

Two types of surface electrodes are being used in SEMG signal acquisition [10,23]. Both have their own merits and demerits.

3.4.1 Passive EMG electrodes

Passive electrodes are normally used more than 80% in surface EMG signal acquisition as they are cheap and easy to manufacture. Gelled surface electrode is one of its examples. Major problem of usage of passive electrodes is that they require special skin preparation before application of these electrodes. Another problem is that signal amplification/conditioning circuitry is not directly connected with passive electrodes but with the help of wires, which induced movement artifacts in Raw EMG signal.

Figure 3.5 Passive EMG electrode

3.4.2 Active EMG electrodes

Active electrodes are directly connected to the amplifier/signal conditioning circuitry. Active electrode is used due to safety and also no special requirement of skin preparation before its usage [2, 23]. The active electrodes resist surrounding noise better than passive electrodes.

Figure 3.6 Active EMG electrode

3.5 EMG Signal Acquisition Circuitry and Configuration

EMG signal acquisition is a tedious job as amplitude of signal is very weak and we need to amplify the received signal and also to eliminate the different noises (power line noise, motion artifacts, movement artifacts and ambient noise). To acquiring EMG signal, the best possible solution is use of differential amplification techniques. The main reason of such choice is due to its CMMR characteristics. This cancels out the noise and further amplify the differential signal. Another reason of usage of differential amplification is that presently available Instrumentation amplifier (differential amplifier) has very high input impedance and very low output impedance. Ideally, a differential amplifier has infinite input and zero output impedance. A classic three amplifier technique is being used in modern instrumentation amplifiers for differential amplification as highlighted in Figure 3.7. The instrumentation amplifier carries out differential amplification. Noise signal, which is common at both points e.g. power line interference etc. are eliminated. Common mode rejection ratio (CMRR) is the measure to check the ability of IC to reject signals common to both inputs. A CMRR of 90 dB is sufficed for elimination of common signals for instrumentation amplifiers. But there are certain reasons for not pushing the CMRR to the limit, as the electrical noise detected by the electrodes may not be in phase [6]. Only one resistor (Rgain) is used to select desired gain otherwise special attention is required on accurate resistor matching. The gain equation and output equation of the instrumentation amplifier is given in Equation (3.1) and (3.2).

$$Gain=(1+2*R_1*Rgain)*R_3*R_2 \quad (3.1)$$

$$Vout=(V2-V1)\times Gain \quad (3.2)$$

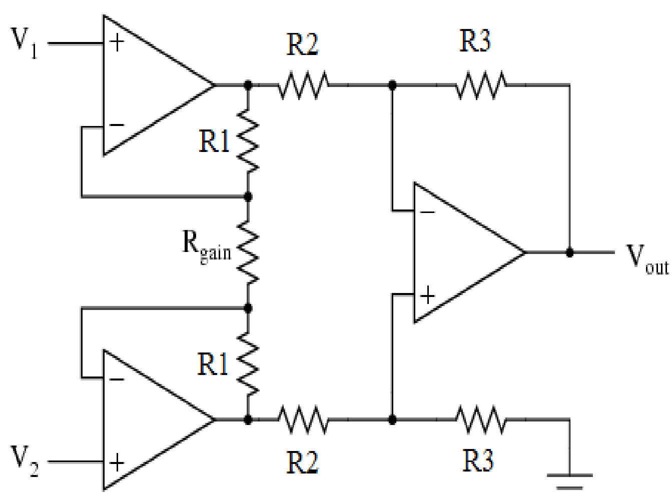

Figure 3.7 Three amplifier instrumentation amplifier

However Paulo Roberto Stefani Sanches et al; [24] used commercially available Field Programmable Analog Arrays (FPAAs) to develop an innovative biomedical application.

3.5.1 Monopolar Configuration

In this configuration, only one electrode along with a reference electrode is used for recording the SEMG signal [9,23]. This strategy is very simple but not being used commonly as it records all electrical potentials present near the detecting electrode so actual muscle activity can't be ascertained with such configuration [9]. Monopolar arrangement of electrode is shown in the below figure

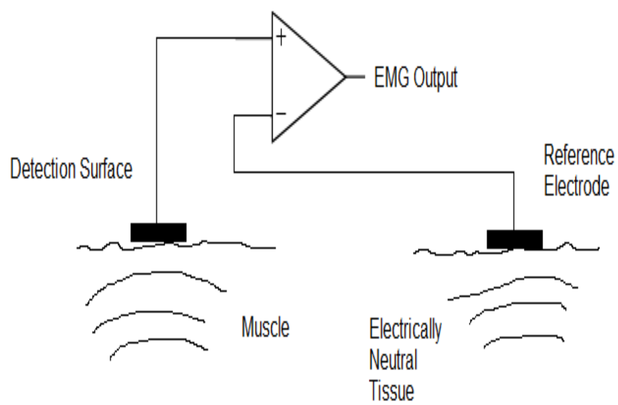

Figure 3.8 Monopolar signal acquisition technique

3.5.2 Bipolar Configuration

In this configuration, we use two electrodes to record the EMG signal with reference electrode[9]. Signal coming from both electrodes are further fed into differential amplifier. Differential amplifier here serves two purposes. One is cancellation of common signal detected at both electrodes and second amplify the remaining signal [9,23]. The distance between the two electrodes is very critical and should be 1 cm [6]. This is the universal configuration used in SEMG signal acquisition.

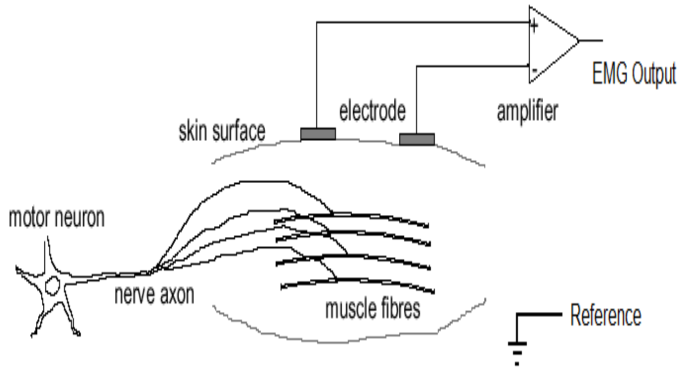

Figure 3.9 Bipolar signal acquisition technique

3.6 Interim Conclusion

In this chapter non-invasive method for EMG detection i.e. Surface EMG was described. All the factors that affect SEMG while recording were discussed. Its advantages and disadvantages were presented. Electrodes used to detect these myoelectric signals and their types were discussed. At last the electrode configurations used to detect SEMG signals was discussed. These configurations help to reduce noise. In the following chapters, design and implementation of the active sensor for detecting SEMG signal is discussed. The signals captured were processed and presented in the last chapter.

CHAPTER 4: ACTIVE SEMG SENSOR DESIGN / FABRICATION METHODOLOGY

This chapter deals with the development of simulink model for further fabrication of active SEMG sensor, its block diagram, schematic of sensor and brief description of important components used for acquiring the SEMG signals. A novel Simulink model has been developed, which mimics various elements of an active SEMG sensor. By using this model, low/high/notch filters are designed and optimized. The model is also used to simulate the effects of these filters on power spectral density (PSD) of the EMG signal. On the basis of simulation results, instrumentation of surface EMG sensor is designed and fabricated.

4.1 Matlab Simulink Model

Matlab Simulink is a powerful tool for simulation of any system and proven to be very beneficial for this research in designing of an active SEMG sensor due to its DSP toolbox. Various filter blocks used in this model have an array of parameters. By manipulating those concerned parameters, the effect on EMG spectrum against those parameters can be analyzed. Effect of different cutoff frequencies of filters (high/low/notch) on power spectral density (PSD) and FFT spectrum of EMG signal can be observed. A novel Simulink model is developed to mimics various filters of an active SEMG sensor as highlighted in figure 4.2 to figure 4.6, used in signal conditioning of raw EMG signal. On the bases of satisfactory results of simulink model, these filters are incorporated in fabrication of active SEMG sensor. Similarly Yinfeng Fang et al; [25] propsed a novel graphic presentation of forearm SEMG signal. Wavelet transform (WT) is suggested by Jolanta Pauk [26] for local analysis of non-stationary and fast transient signal. Wokeun Youn and Jung Kin [27] proposed a compact-size and a wireless surface EMG (electromyography) measurement system.

4.1.1 Data Acquisition of Online Raw EMG Signal

A Matlab Simulink model is developed to design an active SEMG sensor. It is used to simulate the effect of cut-off frequencies of different low/high/notch filter on PSD of real single activity source of EMG signal. Real EMG signal is acquired from McGill KC, Lateva ZC, Johanson ME. Validation of a computer-aided EMG decomposition method. Proc IEEE Eng Med Biol Soc Conf, 4744-4747, 2004. [The data are available as dataset R002 at http://www.emglab.net]. It is a monopolar needle and fine wire isometric contraction. Mcgill KC, VA RR&D Ctr, Palo Alto, US. Transformation of this dataset, in the form of an array of data in Matlab, is done with the help of emglab1.03 software and store this data in Matlab workspace as a variable with the help of following code.

```
[EMGSignal, FS] = getdata ('D:\emg\emglab1.03\sample data\R00203.dat')
y1=EMGSignal(1:131072,3)
Fs = FS(1,1)       % Sampling frequency
```

4.1.2 Transfer Function of Discrete Filters

To design SEMG sensor for prosthesis control, most important step is effective signal processing of raw SEMG signal.

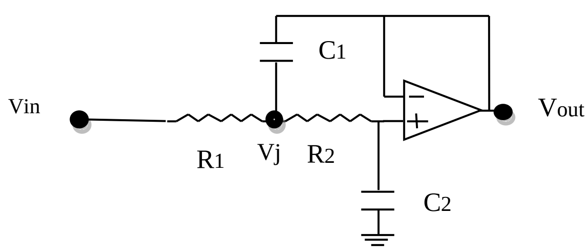

Figure 4.1 2nd order Sallen key low pass filter

First of all transfer function of Sallen- Key low pass filter is derived with the help of following relations :-

$V_j = I_{C2}R_2+V_{out}$ (4.1)

$V_j= V_{out}R_2C_2s+V_{out}$ (4.2)

$V_j= V_{out}(R_2C_2s+1)$ (4.3)

The sum of the currents at node V_j is:

$I_{C2}=I_{C1+}I_{R1}$ (4.4)

$V_{out}/(1/ sC_2)=(V_{in}-V_j)/R_1 + (V_{out}-V_j)/(1/ sC_1)$ (4.5)

$sR_1C_2V_{out}= V_{in}-V_j+ sR_1C_1(V_{out} - V_j)$ (4.6)

Substituting for V_j

$sR_1C_2V_{out}= V_{in}- V_{out}(R_2C_2s +1)+ sR_1C_1V_{out} -sR_1C_1(R_2C_2s+1)$ (4.7)

$V_{out}(sR_1C_2+ V_{out}(R_2C_2s +1)+ sR_1C_1 (R_2C_2s +1)- sR_1C_1)= V_{in}$ (4.8)

$V_{out}(s^2R_1 R_2 C_1C_2+ s(R_1C_2+ R_2C_2)+1)= V_{in}$ (4.9)

$H(s)= V_{out}/V_{in}$ (4.10)

Finally transfer function of Sallen- Key low pass filter is:-

$H(s)= [1/R_1R_2C_1C_2] / [s^2+s(1/R_2C_1+1/R_1C_1)+1/R_1R_2C_1C_2]$ (4.11)

$W_0= \sqrt{(1/R_1R_2C_1C_2)}$ (4.12)

$Q=1/2 \sqrt{(C_1/C_2)}$ (4.13)

Here

W_0=Natural frequency in rad/sec.

Q=Quality factor

Transformation of this low pass active filter to a high pass filter can be done with the following substitutions:-

$sC=1/R$ (4.14)

Thus, the transfer function for a unity gain high pass Sallen-Key filter is:

$H(s)= [s^2] / [s^2+s(1/R_2C_1+1/R_2C_2)+1/R_1R_2C_1C_2]$ (4.15)

$W_0= \sqrt{(1/R_1R_2C_1C_2)}$ (4.16)

$Q=1/2 \sqrt{(R_2/R_1)}$ (4.17)

Transfer function of twin T notch filter is:-

$H(s)= [s^2 + (1/R_1C_1)^2] / [s^2+4s(1/R_1C_1)+ (1/R_1C_1)^2]$ (4.18)

$W_0=1/R_1C_1$ (4.19)

$f_c=1/ [2*3.142* (R_1C_1)]$ (4.20)

Transfer function of smoothing filter is:-

$H(s)= [(1/R_1C_1)] / [s +(1/R_1C_1)]$ (4.21)

$W_0=1/R_1C_1$ (4.22)

Main focus is to develop SEMG sensor, so we require a suitable RC values for different filters involved in signal conditioning. By using those RC values, transfer function of high/low/notch filters in S-domain is evolved for using in simulink model as mentioned in equation (4.23), (4.25) and (4.27) respectively.

As acquired data of real EMG signal for simulation purpose is in discrete form so we also require a transformation of these transfer function from S to Z-domain. For conversion of transfer function from S-domain to Z-domain, following matlab based program is used:-

```
num=[1 0 97900.85]                % Numerator coefficient of tfr function in S-domian
 den=[1 1251.56 97900.85]         % Denominator coefficient of tfr function in S-domian
 sys=tf(num,den)
discrete_sys=c2d(sys,0.0001)      %Sampling frequency is 10000 Hz.
```

Transfer function of Sallen - Key high pass (f_c=20Hz) second order active filter in S and Z-domain is:-

$$H(s)= [s^2]/[s^2 + 181.81 s + 16233.766] \qquad (4.23)$$

$$H(z)= [z^2 - 2 z + 0.999] / [z^2 - 1.982z + 0.9823] \qquad (4.24)$$

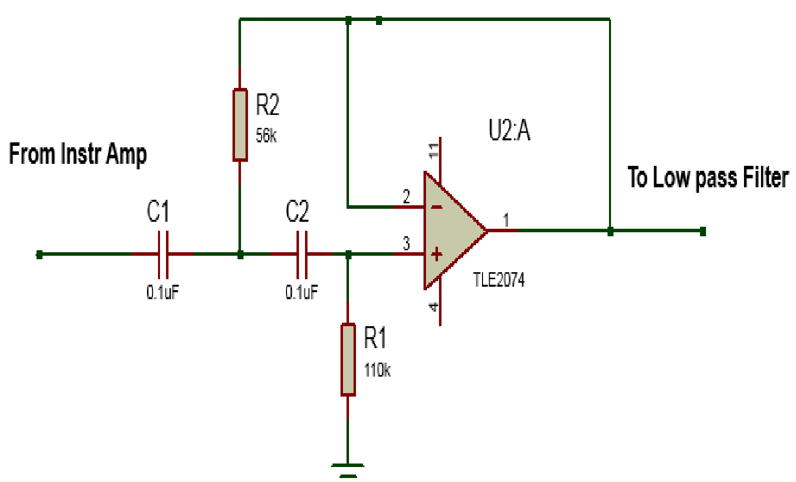

Figure 4.2 High pass filter at the slope rate of -12dB/octave.

Transfer function of low pass (f_c=490Hz) second order active filter in S and Z-domain is:-

$$H(s)= (9391435) / [s^2 +s(4132.23) +9391435] \qquad (4.25)$$

$$H(z) = [0.04079\, z + 0.03554] / [z^2 - 1.585z + 0.6615] \quad (4.26)$$

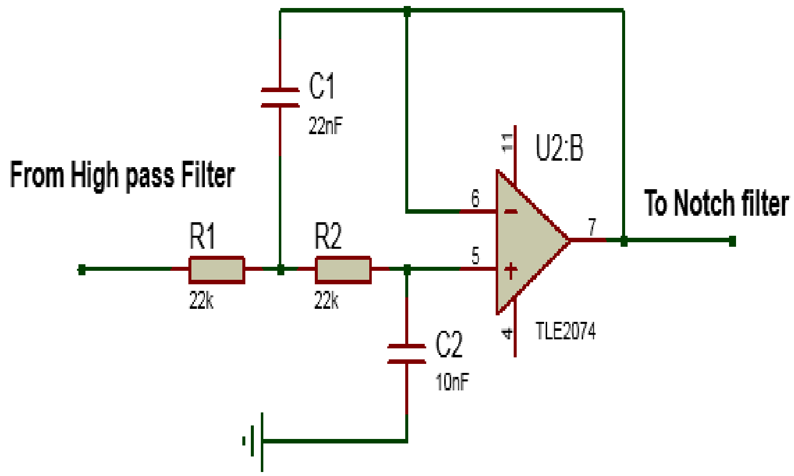

Figure 4.3 Low pass filter at the slope rate of -12dB/octave.

Twin-T notch filter is used to remove power line noise source from EMG signal. Transfer function of twin-T Notch filter in S and Z-domain is:-

$$H(s) = [s^2+97900.85] / [s^2+1251.56s+97900.85] \quad (4.27)$$

$$H(z) = [z^2 - 1.999z + 1] / [z^2 - 1.881z + 0.8824] \quad (4.28)$$

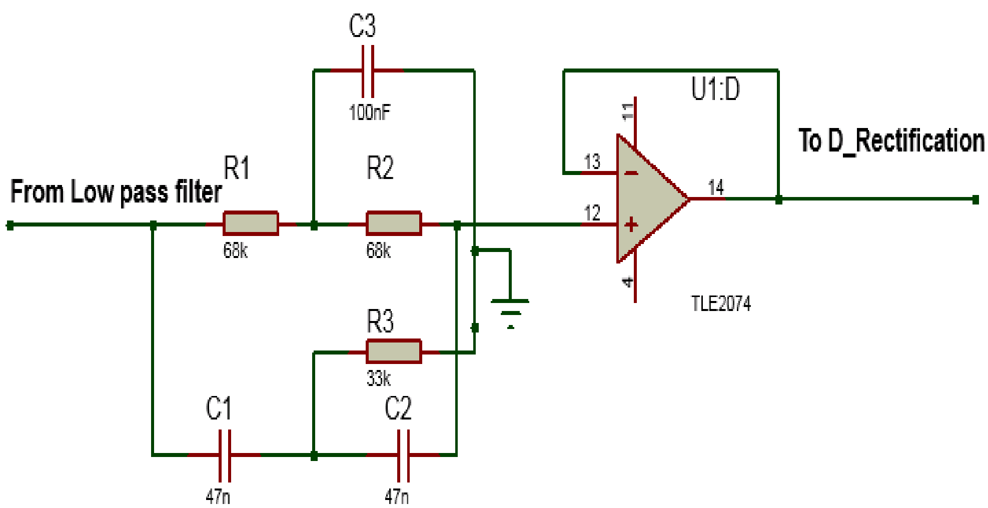

Figure 4.4 Twin T notch filter used in sensor fabrication.

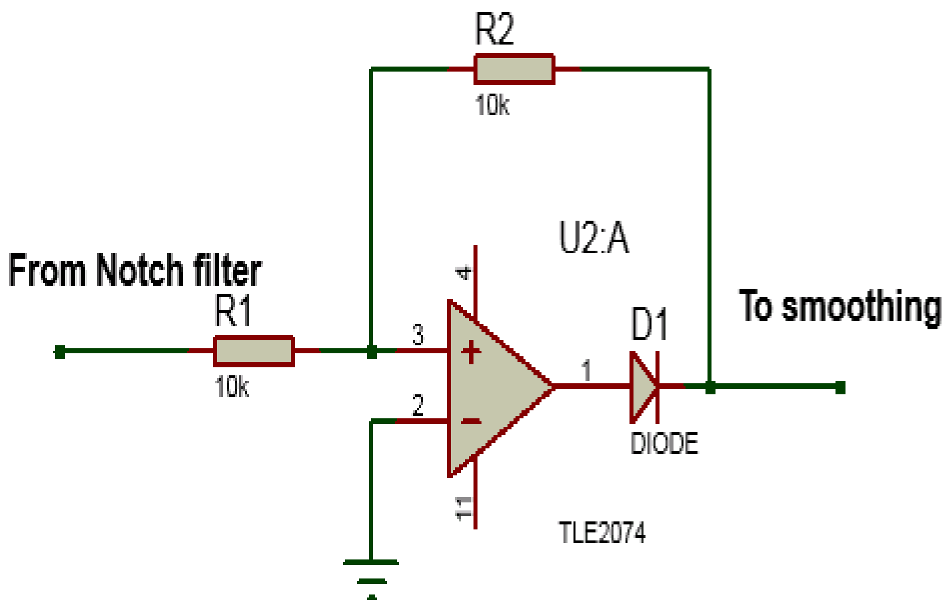

Figure 4.5 Double rectification circuit used in sensor fabrication.

Transfer function of low pass filter (f_c=2.13Hz) for envelopment of signal in S and Z-domain is:-

$$H(s)= [14.7] / [s+14.7] \quad (4.29)$$

$$H(z)= [0.001469] / [z - 0.9985] \quad (4.30)$$

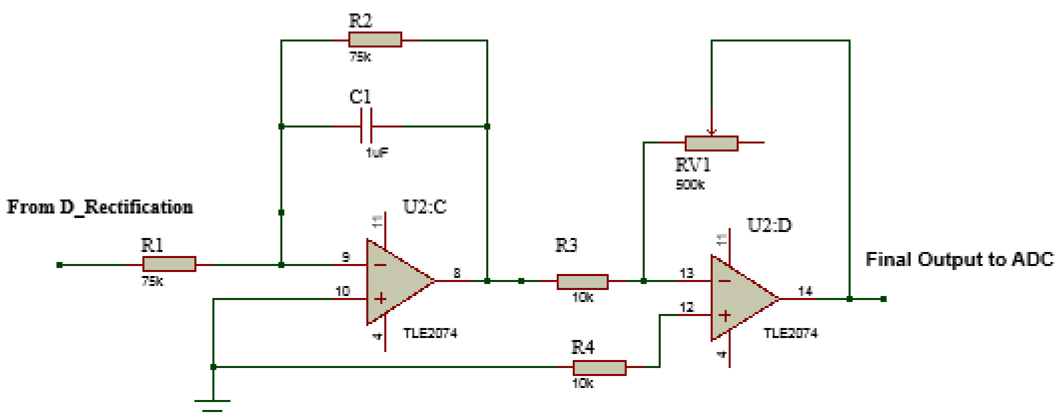

Figure 4.6 Smoothing of EMG signal at 2.13 Hz.

4.1.3 Development of Simulink Model

Real EMG signal is used in this model to simulate the effect of different stages involved in designing of SEMG sensor. It acquires discrete data set from Matlab workspace and through

Gain block processed it through 3x discrete filter blocks for high/low/notch filters respectively. Transfer functions for high/low/notch filters as mentioned in equation (4.24), (4.26) and (4.28) respectively are used in discrete transfer function blocks. As data is in discrete form, the fixed step discrete configuration is used in this simulation. Signal is firstly high pass filtered (f_c=20Hz) then processed through low pass filtered (f_c=490Hz) and lastly fed through a notch filter to eliminate f_c=50Hz power line noise. The amplitude of SEMG signal is random in nature [6]. Its amplitude swings rapidly between above and below zero volts. In digital signal processing, to remove the rapid fluctuation in the signal, generally the average of the random values is obtained. It has resemblance to smoothing operation in analog but simply averaging of the random values of the signal might produce meaningless results. Thus, before averaging out the

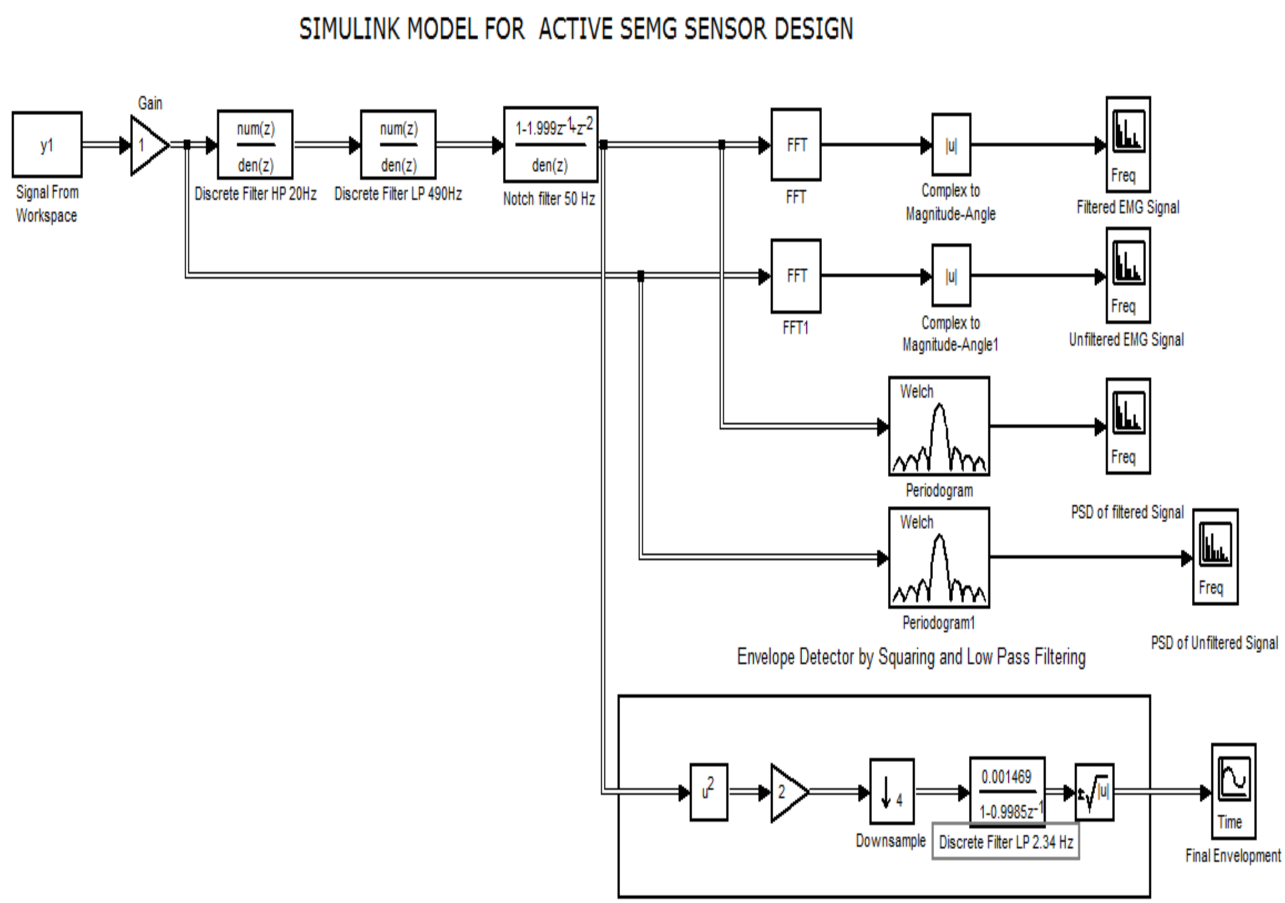

Figure 4.7 Matlab Simulink model for designing SEMG sensor.

signal, rectification of the EMG signal is mandatory. Normally, the full-wave rectification is carried out so that all the energy of the signal could be retained. For double rectification and envelopment, "squaring and low pass filtering" technique is used. FFT block shifts the data from time domain to frequency domain and FFT spectrum is shown on Vectorscope. Periodogram block using Hanning window generates PSD.

4.2 Block Diagram of Fabricated SEMG Sensor

On the basis of successful simulation results of simulink model, SEMG sensor is developed by incorporating the RC values used in transfer functions of high/low/notch filters. There are total eight stages involved practically in hardware of actual SEMG sensor for signal processing. Figure 4.8 shows the block diagram of the developed active SEMG sensor.

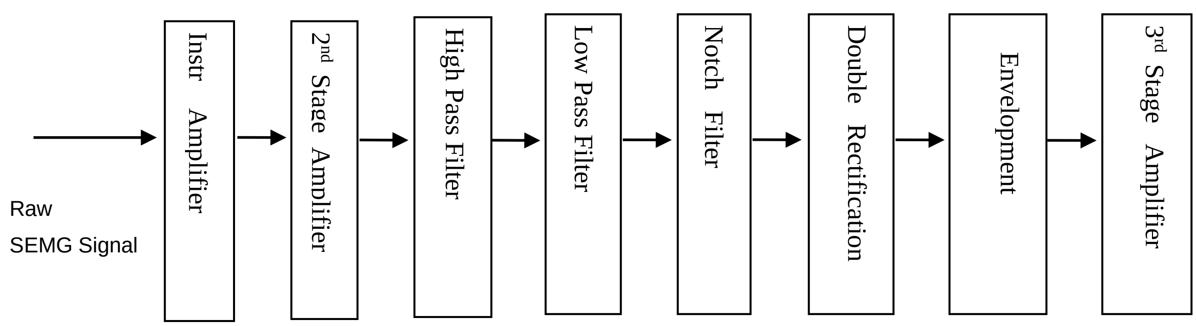

Figure 4.8 Block diagram for development of active SEMG sensor

4.2.1 Instrumentation Amplifier

Differential detecting configuration is used to remove power line sources in this active electrode. The instrumentation amplifier uses differential detecting configuration, which accepts a differential input voltage. Only one resistor (R_g) is used in instrumentation amplifier to control the gain of amplifier. It produces an amplified difference of the two input voltages. It has very high input impedance and very low output impedance. The SEMG signal is detected by two electrodes placed at a distance of 10mm apart [6] and architecture of instrumentation amplifier subtracts the two signals and then amplifies the difference. Different Instrumentation amplifier ICs are being used worldwide. Basing on the parameters, different ICs are evaluated as shown in table 4-1.

Table 4-1 Different parameters of worldwide available Instrumentation Amplifier ICs

Ser #	Parameters	Devices							
		INA 121	INA 118	AD8226	INA826	INA 128	INA 131	AD 620	AD8221
1	Input Impedance (Ω ‖ pF)	10^{12} ‖ 2	10^{10} ‖ 1	$0.8*10^{09}$ ‖ 2	20^{10} ‖ 1	10^{10} ‖ 2	10^{10} ‖ 6	10^{10} ‖ 2	10^{11} ‖ 2
2	CMRR (dB)	106	110	86	104	120	110	100	120
3	Low input offset voltage (µV)	±200µV	50 µV	100 µV	150 µV	50 µV	50 µV	50 µV	25 µV
4	Low input offset drift (µV/°C)	±2	0.5	±2	±2	0.5	0.25	0.6	0.3
5	Low input noise(nV/√Hz)	20	10	22	18	8	12	9	8
6	Low input bias current	±4pA	5nA	20nA	35nA	5nA	2nA	1nA	0.4nA
7	Low quiescent current (µA)	±450	350	350	200	700	2.2mA	700	350
8	Supply Range	±2.25V to ±18V	±1.35 to ±18V	±1.35 V to ±18 V	±1.35 to ±18V	±2.25 to ±18V	±2.25 to ±18V	±2.3 to ±18V	±2.3 to ±18V
9	Input Protection upto	±40V	±40V	±35V	±40V	±40V	±40V		±35V

Due to differential detecting configuration, common signal will be cancelled out and signals that are different at the two sites will have a "differential" and then will be amplified as per desired gain. On the other hand, signal that initiates far away from the detection sites will appear as a common signal, whereas signals in the immediate vicinity of the detection sites will be differential signal.

4.2.2 Filters

Electromyographic (EMG) activity is mainly the generation of biopotential signal due to muscle action. These signals are contaminated with various noises [6]. These noises must be eliminated through different design/filtering techniques such as usage of active sensor coupled with high pass filter, low pass filter and notch filter [6]. The strength of these signals is very weak and lies in between 1-10 mV [6]. Generally frequency range of these signals is from 0-500 Hz [6] and most dominant is in between 50-150 Hz [6], where signal strength is very significant [6]. EMG signal processing is a tedious job, where one must be very careful during filtering of EMG signal. Neither noise source still be part of signal nor part of actual EMG signal be removed. Ambient noise generates from the 50 Hz radiation from power sources [6]. The amplitude of ambient noise signal is thrice than the EMG signal where as frequency range of motion artifacts/ inherent instability of EMG signal lies in between 0-20 Hz [6]. These two noises can be eliminated with the help of proper high and notch filters in designing of sensor. Response of EMG signal is quasi-random. Due to this nature of the firing rate of the motor units, frequency components of SEMG signals ranging from 0 and 20 Hz are particularly unstable. Because of this unstable behavior, this range of signal be considered as unwanted noise and remove them from the signal by using high pass filter. Signal is firstly high pass filtered (f_c=20Hz) then processed through low pass filtered (f_c=490Hz) [28] and lastly fed through notch filter to eliminate f_c=50Hz power line noise.

4.2.3 Circuit Diagram

"Altium Designer 2014" is an Electronic design automation software used for PCB, FPGA and embedded software design. It has vast associated library. Its schematic capture module provides electronics circuit editing and used for schematic of sensor. Instrumentation amplifier INA 118 is used as Pre amp basing on the parameters highlighted at table 4-1. Dry silver electrodes are used in this sensor, so to avoid saturation of Instrumentation amplifier, 200 gain is set. AC coupling capacitor (10 nF) is used to remove DC offset from amplified signal. As received EMG signal is still weak, so to further amplify it, 2^{nd} stage amplifier (TLE 2074 op amp) having (gain=20) is used. Then signal conditioning of raw signal is carried out through 2^{nd} order HP /LP filter. Twin T notch filter is used to remove ambient noise [29]. Another Ac coupling capacitor (10 nF) is used to remove DC components. Then D/rectification of signal is carried out to flip the negative peaks into positive to maintain signal strength. To get the envelopment of signal, Smoothing of signal is carried out through low pass filtering at 2.13 Hz. Finally signal is amplified through variable gain max upto Gain=50.

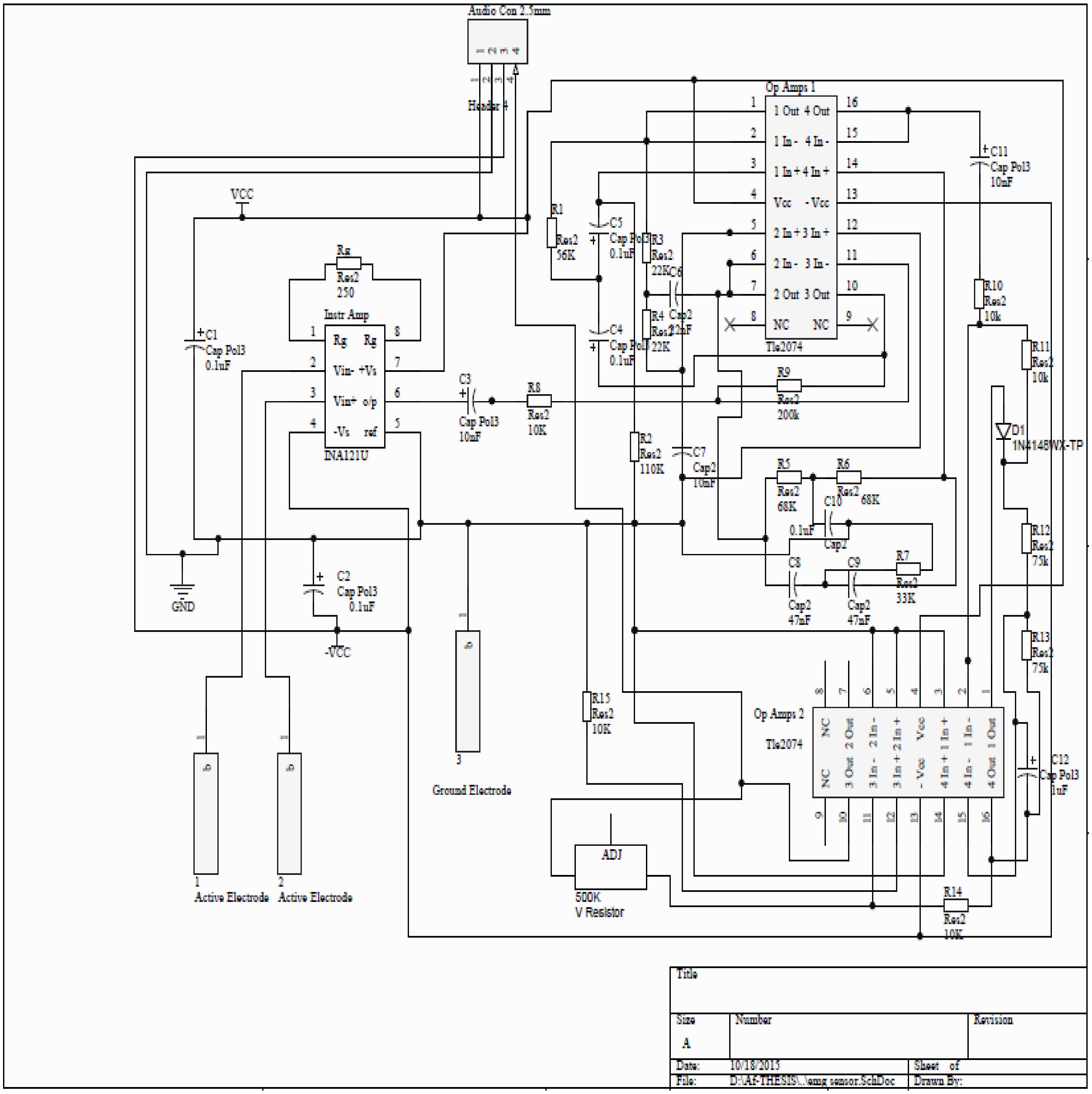

Figure 4.9 Schematic of the developed sensor

4.2.4 PCB of SEMG Sensor

PCB design of this sensor is designed in PCB design module of “Altium Designer 2014”. It has a large associated component footprint library. Sensor is developed in 2xlayers configuration. Size of PCB is 35mmx21mmx1.6mm. Foot prints of few components are also developed in Altium and rest were available in library of Altium.

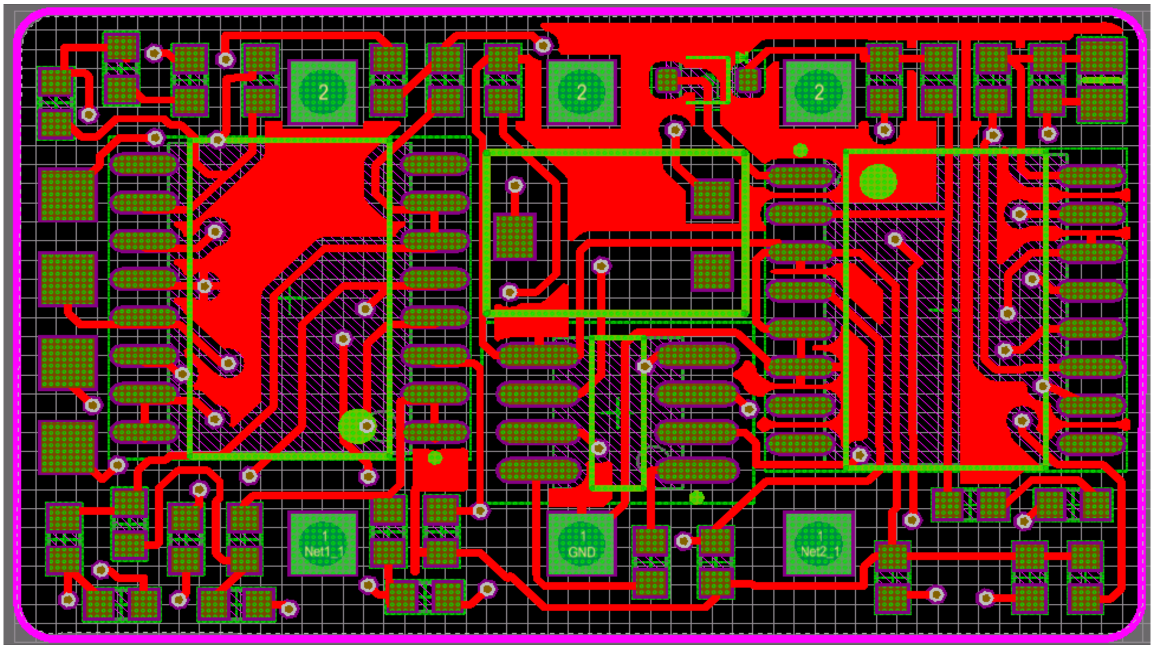

Figure 4.10 Top view of PCB of SEMG sensor

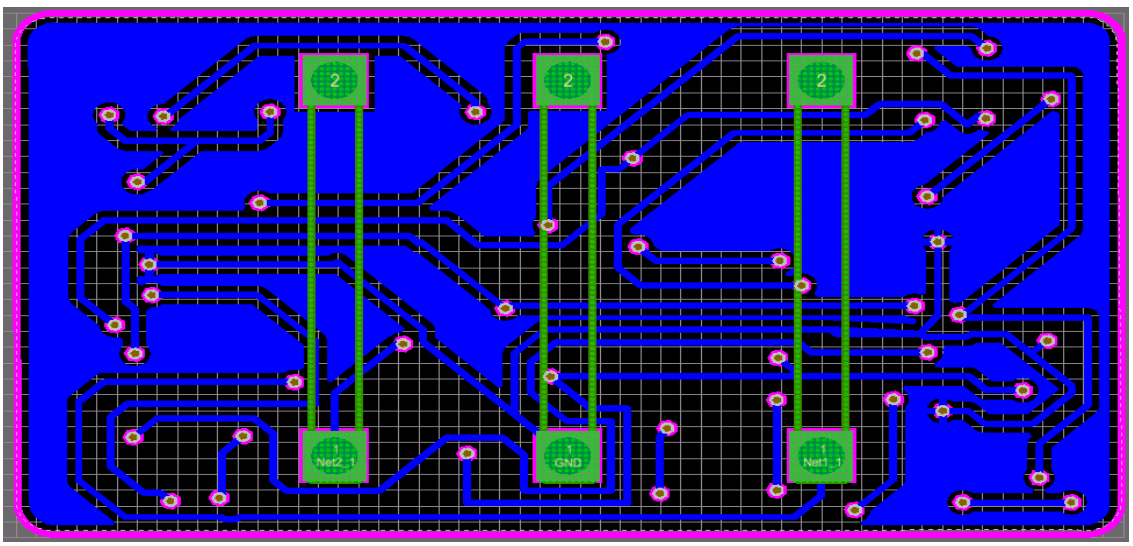

Figure 4.11 Bottom view of PCB of SEMG sensor

4.3 Components Description

4.3.1 Instrumentation Amplifier

INA 118 is used as instrumentation amplifier due to its very high input impedance ($10^{10}\Omega$) and higher CMRR (110dB) as shown in Figure 4.12. Due to very high impedance between skin and electrode, INA 118 is selected because of its very high input impedance [31].Due to its differential amplification configuration, it eliminates the noise from external source. Its gain is set at 200 using external resistor (R_g) to avoid saturation of amplifier. The technical description of the IC is as follows:

Figure 4.12 8-Pin INA118 SOIC

The INA118 is low power instrumentation amplifier used in SMD form keeping in view space constraint. It provides excellent accuracy. Because of its multipurpose three-op amp design and very small size consider it ideal for biomedical applications. This IC can be used with high impedance sources because of its low bias current (5nA). Provision of gain setting from 1V to 10,000V/V with a single external resistor (R_G) is available with this IC. Internal input protection can withstand up to ±40V without damage.

IC gain (G) is set by connecting an external resistor (R_g) according to the equation (4.31).

$$G = 1 + [50k\Omega/R_g] \qquad (4.31)$$

Other features of this instrumentation amplifier are:

- High input impedance: $10^{10}\Omega$
- Low bias current: 5nA
- Low quiescent current: 350µA
- Low input offset voltage: 50µV
- Low input offset drift: 0.5µV/°C
- Low input noise:10nV/√Hz at f = 1kHz (G =100)
- High CMRR: 110dB
- Wide supply range: ±1.35V to ±18V

- Input protection to ±40V
- 8-Pin DIP and SO-8 Surface mount

4.3.2 Tle 2074 Operational Amplifier

This Op Amp is 16 pin quad low noise, high speed JFET input operational amplifier. Chip offset trimming voltage facility is available on this IC for improved DC performance. It also has a wider supply rail increased dynamic signal range to ± 19 V.

Figure 4.13 16-Pin Tle2074 SOIC

Other features of this instrumentation amplifier are:

- Low bias current:20pA
- Low input offset voltage: 5 mV @ 25 C
- Low input noise:11.6nV/√Hz at f = 1kHz
- High CMRR: 70dB
- High input impedance: $10^{10}\Omega$
- Wide supply range: ±2.25V to ±19V
- 16-Pin DIP and SO-8 Surface mount

4.3.3 Silver Electrodes

3xPure silver strips (17mmx5mmx1mm) are used as dry electrodes in this active sensor [32]. 2x strips are used as active electrodes having 10mm inter electrode distance (IED) but 1x strip is used as ground electrode. Variation in IED may lead to change the amplitude of the signal [33] but increasing distance will generate cross talk signal also. These electrodes are used to make electrical contact with the skin to acquire differential EMG signal due to muscle contraction. Common signal between the two active electrodes is rejected due to differential configuration of Instrumentation amplifier. Resultantly differential signal is amplified and pass through different filter circuitry i.e; High/low/Notch .

The reason behind using AgCl electrode is that Cl^- is abundantly available in human body. The chemical reaction took place at electrode – electrolyte junction is given as:-

$$Ag \leftrightarrow Ag^+ + e^-$$

$$Ag^+ + Cl^- \leftrightarrow AgCl \text{ (precipitate)}$$

Ag^+ available on electrode surface pass to the solution at the electrode – electrolyte junction. Ag^+ ions combine with Cl^- ions, already present in solution to form the ionic compound AgCl. AgCl being slightly soluble in water, precipitates out of solution on silver electrode and contributes to AgCl deposit. Thus the half cell potential for this electrode is quite stable for biological systems [12].

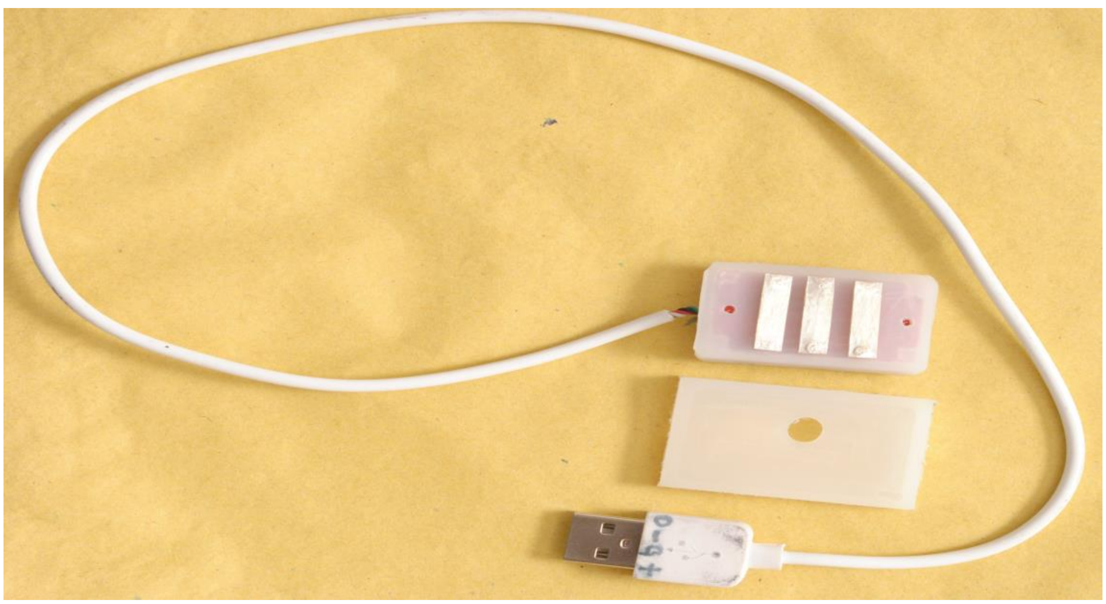

Figure 4.14 Silver electrodes attached directly to Pre-amplifier of SEMG sensor

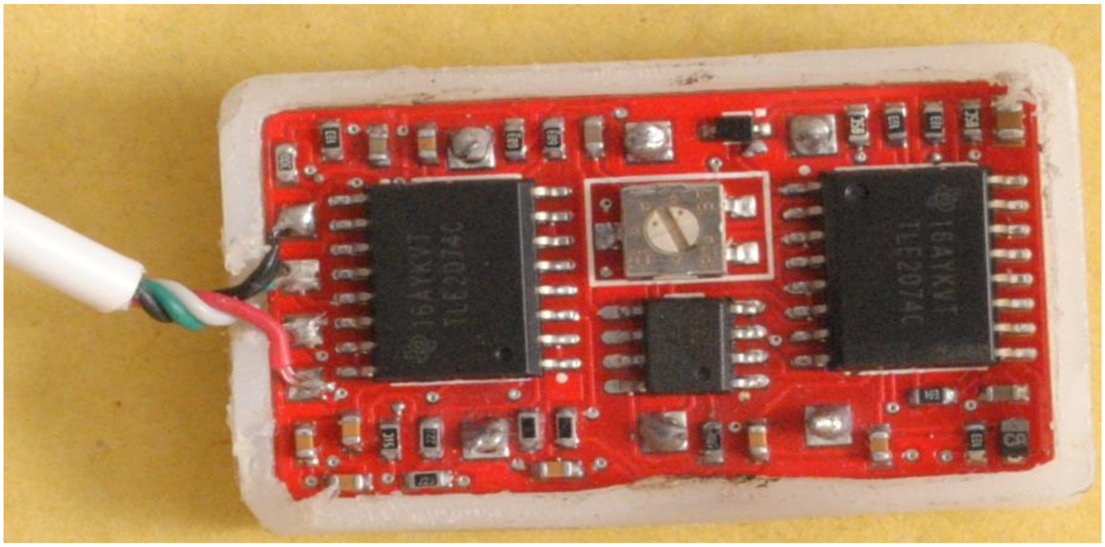

Figure 4.15 Top view of the developed active SEMG sensor.

4.4 LABVIEW

LabVIEW is abbreviated as Laboratory Virtual Instrument Engineering Workbench. It is powerful and highly flexible software for instrumentation and analysis. It is an interactive program development and execution system designed for people, like scientists and engineers. By using terminology, icons and ideas available in this software, scientists and engineers can program their assignments.

Another benefit of LabVIEW is that it is a basically a graphical programming language, using icons instead of huge lines of text code to create any applications. Graphic symbols are used instead of textual language to describe any programming actions. Due to its graphical nature, it is proven to be ideal for test and measurement. It can also be used for automation, instrument control, data acquisition and data analysis applications. It is more flexible than standard laboratory instruments because of software based. Most programming tasks can be easily handled due to its extensive libraries of functions and subroutines without the fuss of pointers, memory allocation, and other arcane programming problems found in conventional programming languages. It also contains application-specific libraries of code for data acquisition, General Purpose Interface Bus, serial instrument control, data analysis, data presentation, data storage, and communication over the Internet.

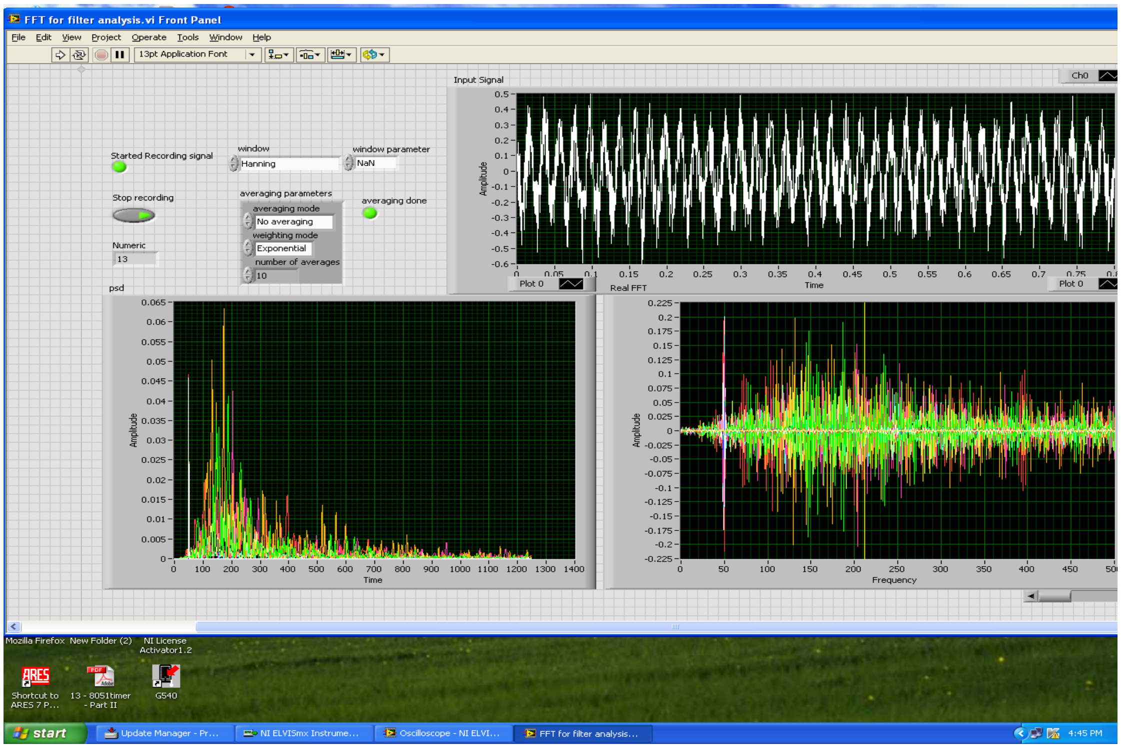

Figure 4.16 FFT and PSD of raw SEMG signal acquired from developed sensor

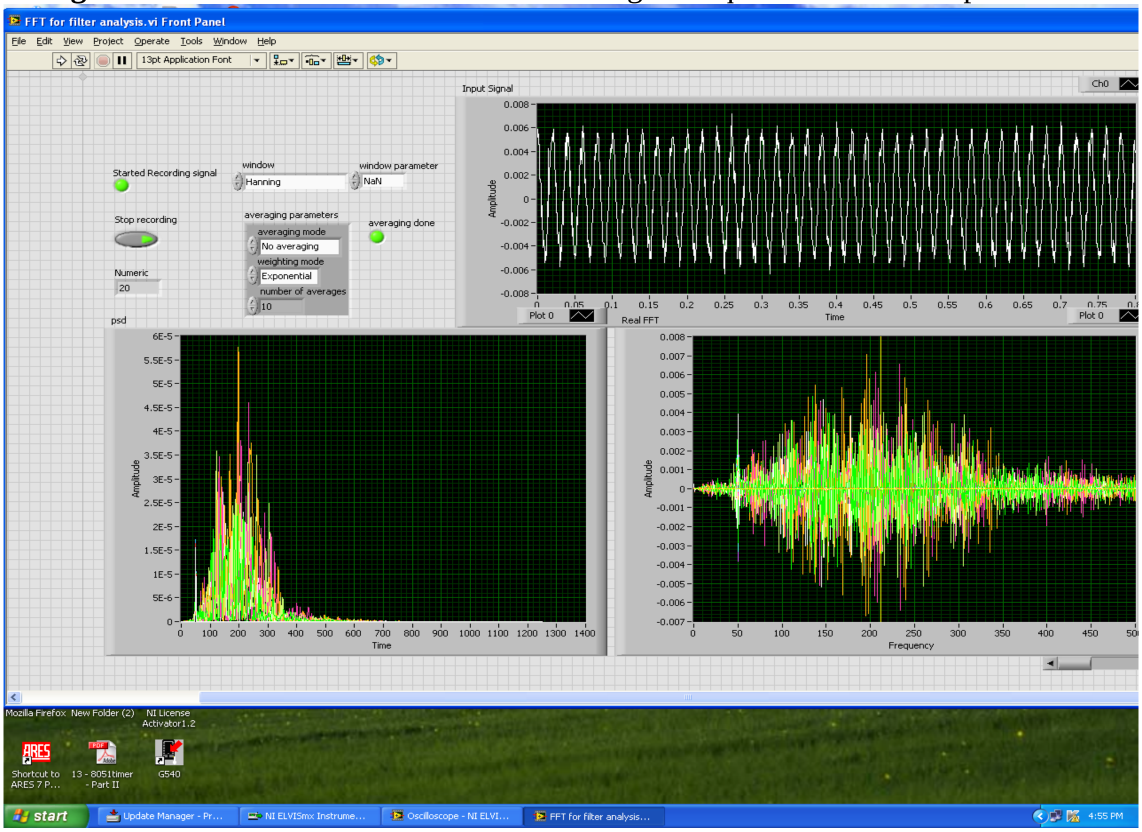

Figure 4.17 FFT and PSD of conditioned signal acquired from developed sensor

4.5 Design of Sensor Enclosure

PCB of active SEMG sensor is required to be enclosed in enclosure and 3xsilver electrodes are also required to be attached with PCB through enclosure. Sensor enclosure is designed according to the dimensions of PCB (35mmx21mmx1.6mm) in PRO Engineers. Figure 4.18 shows the bottom side of enclosure. Dimension of bottom enclosure are as under:

- Length x Width : (37mmx 23mm)
- Thickness of walls: 1mm
- Internal height of walls: 4.5mm
- Dia of holes: 1.6mm

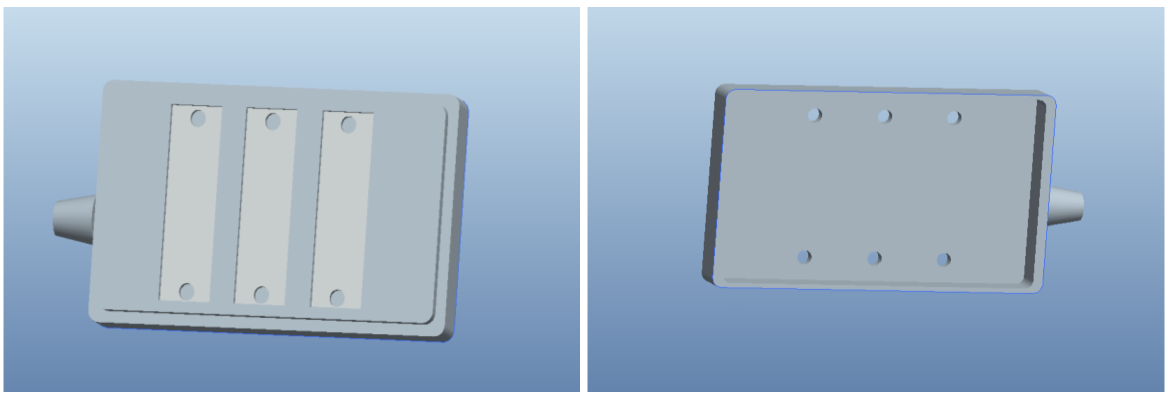

Figure 4.18 Bottom side of sensor enclosure

Top side of sensor enclosure is shown in figure 4.19. Dimensions of top side are as under:

- Length x Width : (39mmx 25mm)
- Thickness of walls: 1mm
- Internal height of walls: 1.5mm
- Dia of holes: 6mm

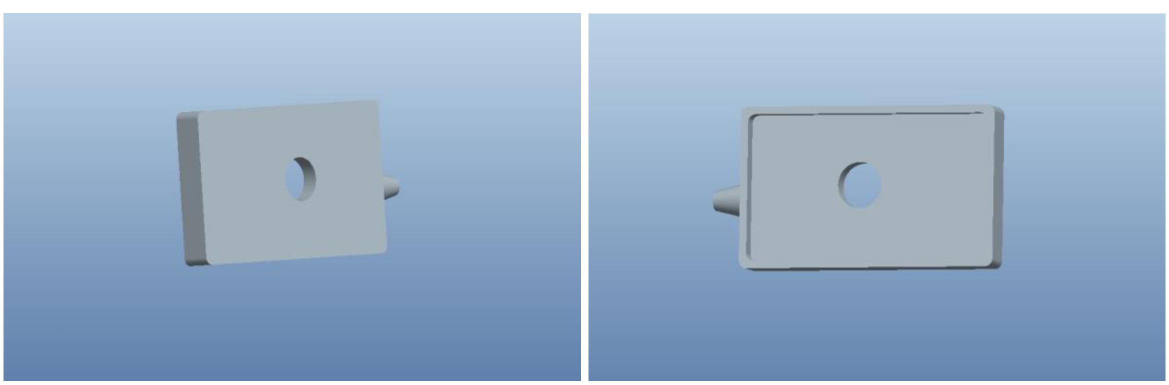

Figure 4.19 Top side of sensor enclosure

4.6 Cost Effect of Fabricated Sensor

Surface mount devices (SMD) are used in this sensor fabrication to reduce the size to bear minimum. Mostly components were not available in Pakistan so resultantly purchased from USA. Tolerance limit of resistors are 1% where as tolerance limit of capacitors are 10%. Cost incurred on fabrication of this sensor is Rs.4495/- if fabricate on mass scale. Detail is highlighted at Table 4-2.

Table 4-2 Detail of components used in sensor fabrication

S/No	Description	Qty Req	Cost Effect (Rupees)
1	Resistor 250 ohm	1	5
2	Resistor 56K	1	5
3	Resistor 110K	1	5
4	Resistor 22K	2	10
5	Resistor 68K	2	10
6	Resistor 10K	5	25
7	Resistor 75K	2	10
8	Resistor 33K	1	5
9	Resistor 200K	1	5
10	Capacitor 0.1 uF	5	50
11	Capacitor 10nF	3	15
12	Capacitor 22nF	1	10
13	Capacitor 47nF	2	20
14	Capacitor 1uF	1	10
15	Diode 1N4148	1	20
16	Tle2074 (16 Pin)	2	1100
17	INA121U (8 Pin)	1	700
18	Trimmer Resistor 500 K Ohm 0.25W SMD	1	90
19	PCB Fabrication	1	300
20	PCB Enclosure	1	300
21	PCB Stuff	1	1000
22	Silver Electrode	3	700
23	USB Wire	1	100
		Total Cost:(Rupees)	4495

CHAPTER 5: RESULTS AND DISCUSSION

This chapter deals with the results, acquired through simulink model by using online available Raw EMG signal and also results achieved from fabricated active SEMG sensor by using real SEMG signal, acquired from human muscle. Moreover SEMG signals were measured from flexor carpi radiali forearm muscles against 5x male subjects at 100%MVC.

5.1.1 Results of Simulink Model

Real raw EMG signal R00203 is utilized in this simulink model. If we analyze the spectral plot of EMG signal in figure5.1, it depicts that band width of raw signal is from 0-1.5K Hz containing intrinsic/extrinsic noises [1, 7].

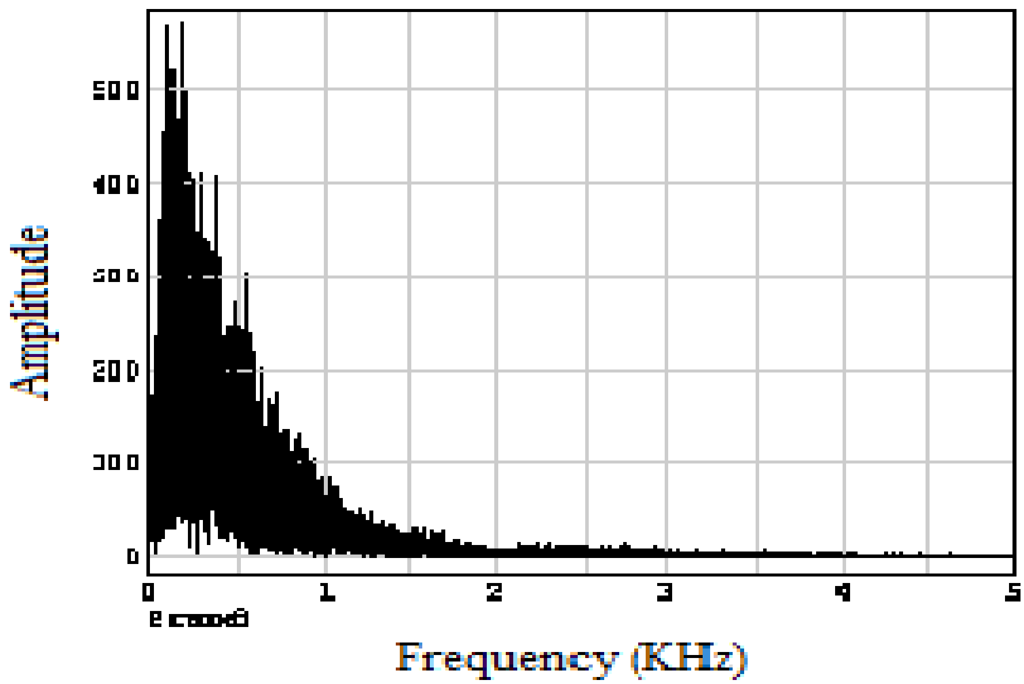

Figure 5.1 FFT Spectrum of raw EMG signal (Amplitude Vs Frequency (KHz)) is acquired from the Simulink model. This spectrum shows that EMG signal contains both intrinsic/extrinsic noises.

Sampling rate of data set was 10K Hz and total 131072 discrete samples are used in this study.

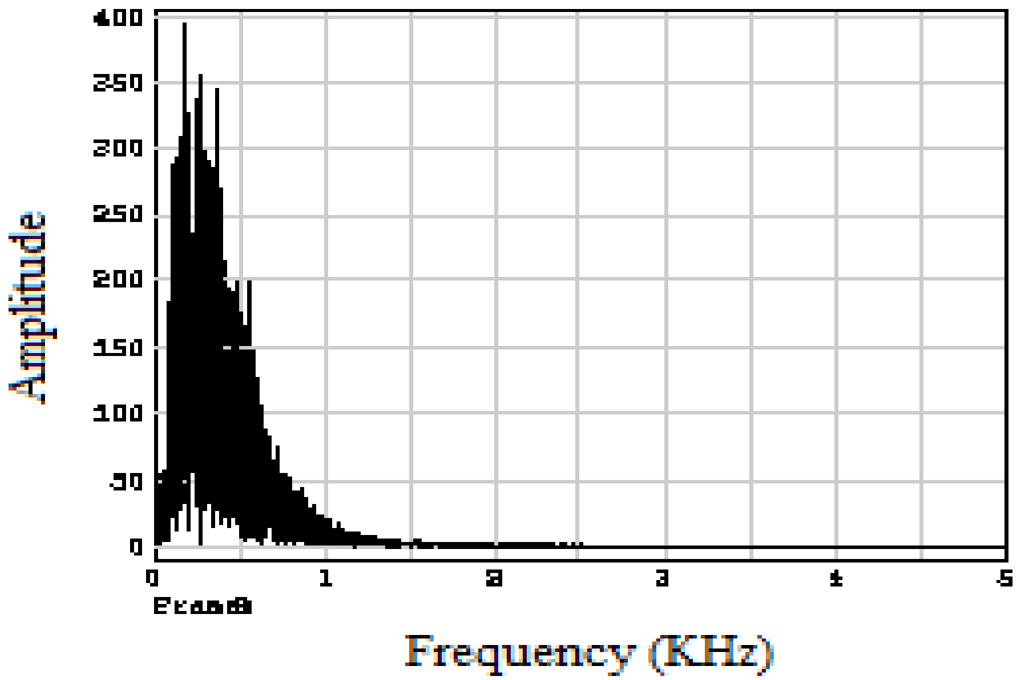

Figure 5.2 Spectrum response of filtered EMG signal against 2nd order high pass filter (f_c=20Hz) and low pass filter (f_c=490Hz)

Similarly, effect of notch filter against 50 Hz frequency is highly evident in power spectral density (PSD) of EMG signal, as shown in Figure.5.3.

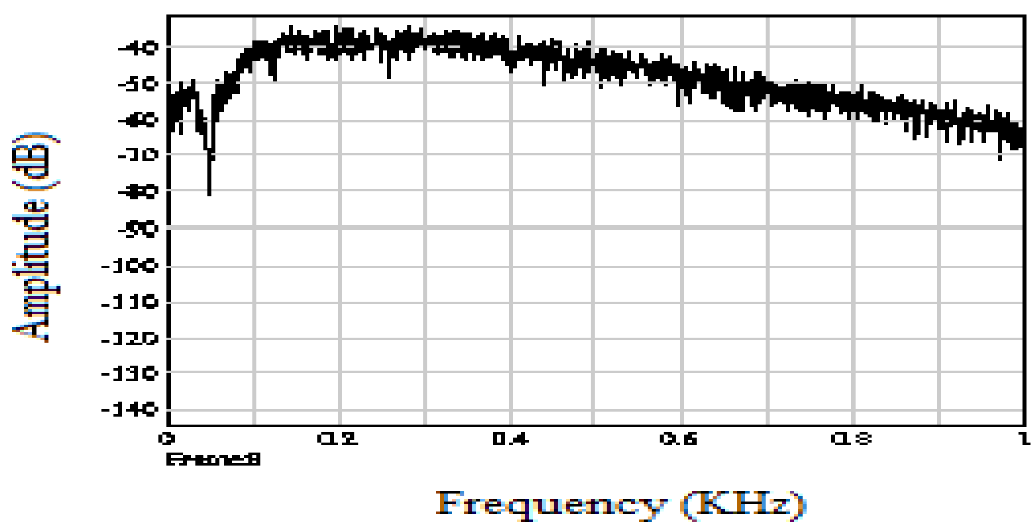

Figure. 5.3 PSD of filtered EMG signal is acquired from this simulink model by using Hanning window in Periodogram block.

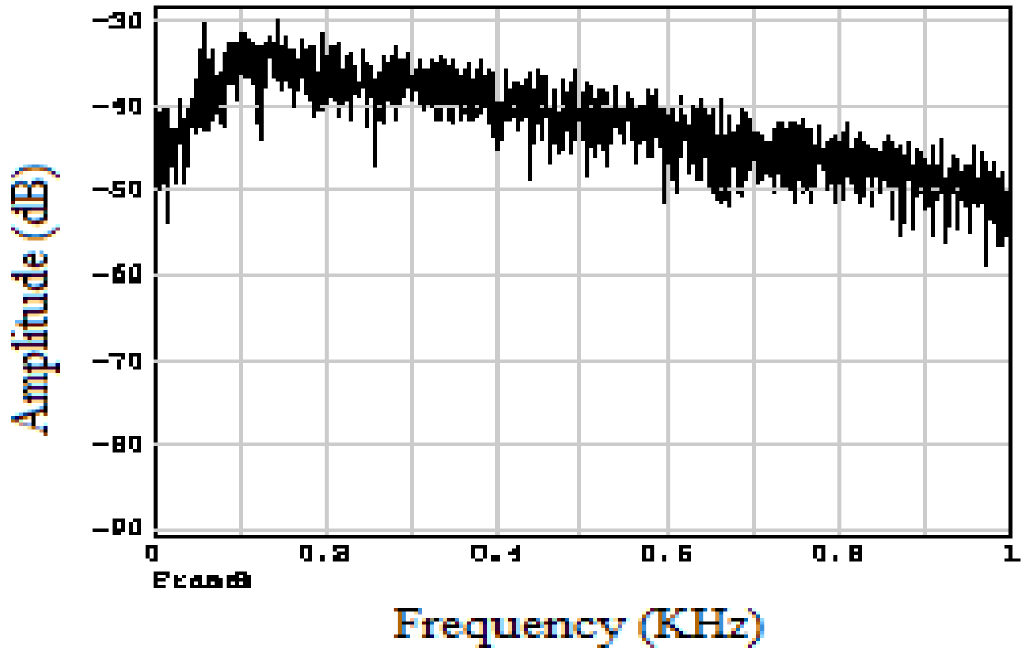

Figure. 5.4 PSD of unfiltered EMG signal is acquired from simulink model by using Hanning window in Periodogram block.

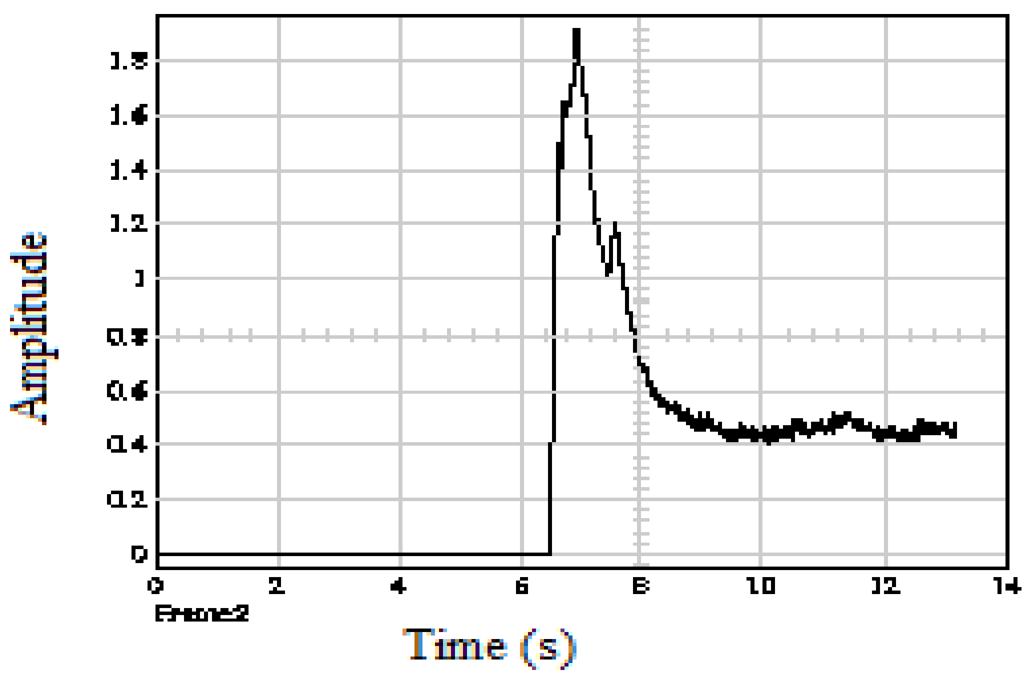

Figure. 5.5 Squaring and low pass filtering unit is used in this model to get smoothing of EMG signal.

5.1.2 Results of Fabricated Active SEMG Sensor

On the basis of successful results of simulink model, active SEMG sensor is developed. SEMG signal response of forearm muscle is :-

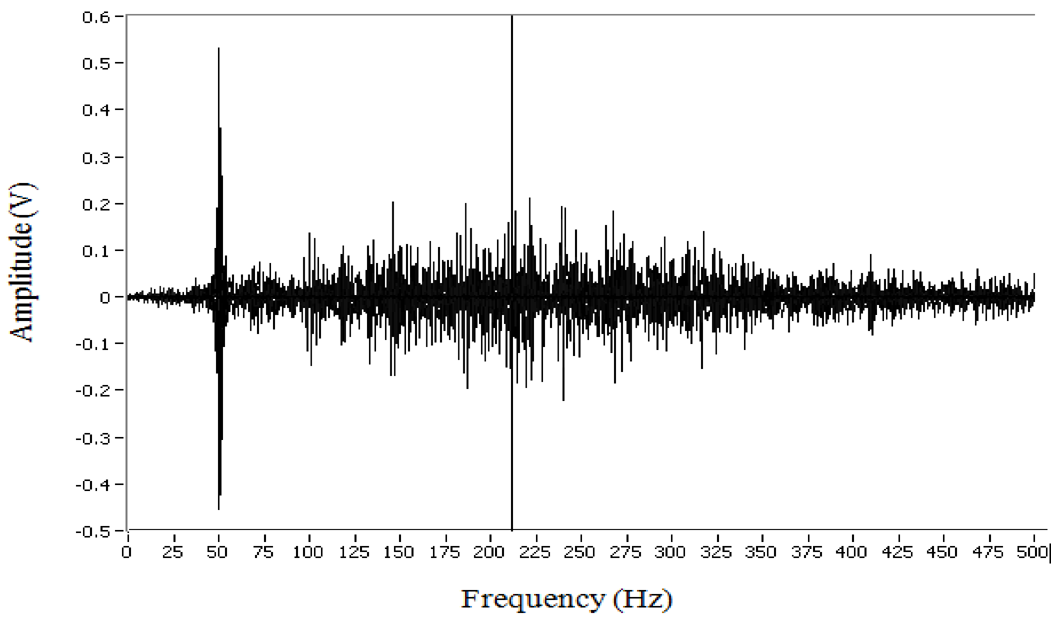

Figure. 5.6 FFT of Raw SEMG signal acquired from fabricated sensor.

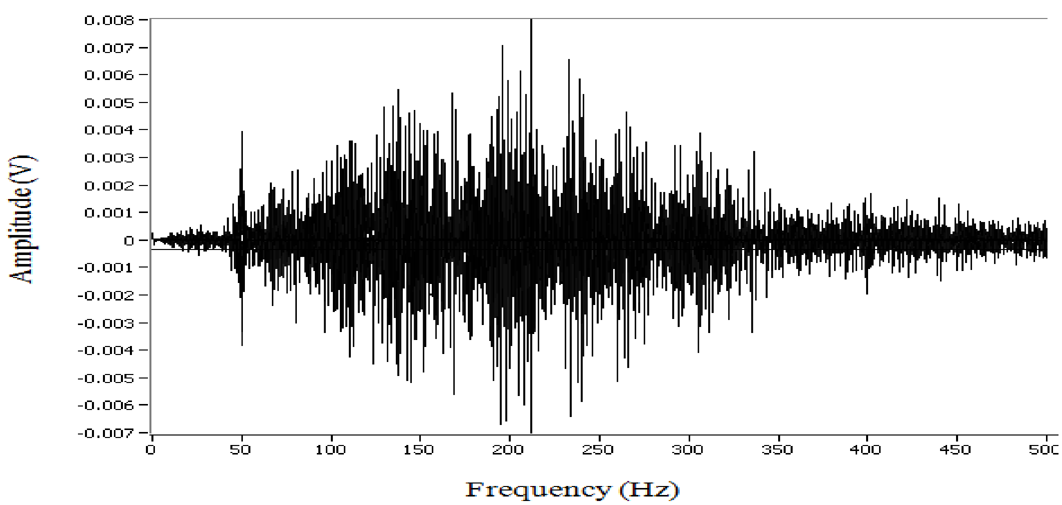

Figure. 5.7 FFT of filtered SEMG signal is acquired from fabricated sensor through Labview software. Filtration of raw SEMG signal is carried out through high, low and notch filters of fabricated SEMG sensor.

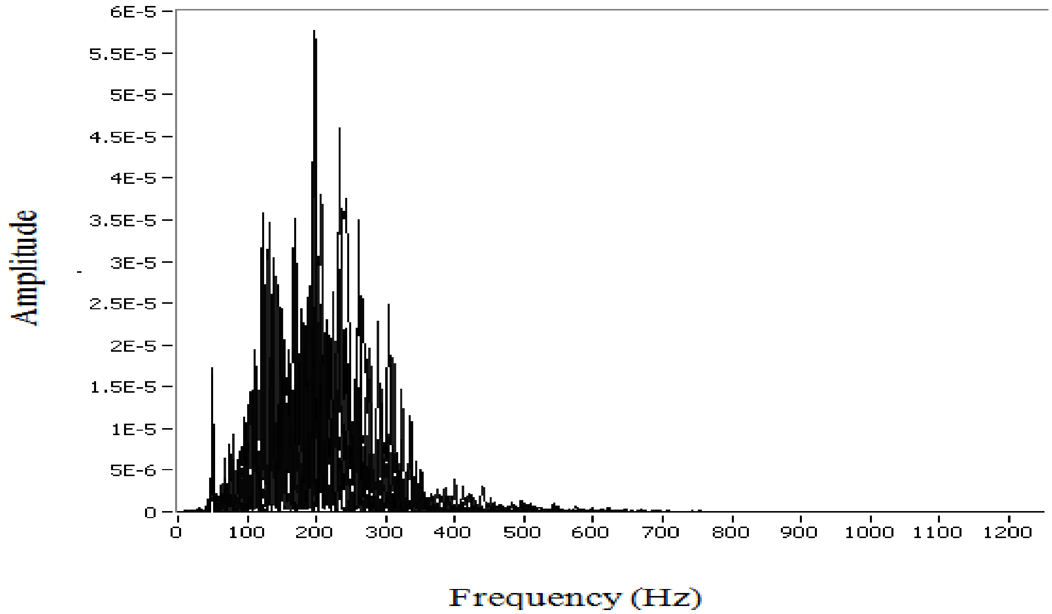

Figure. 5.8 PSD of SEMG signal is acquired from fabricated sensor through Labview software.

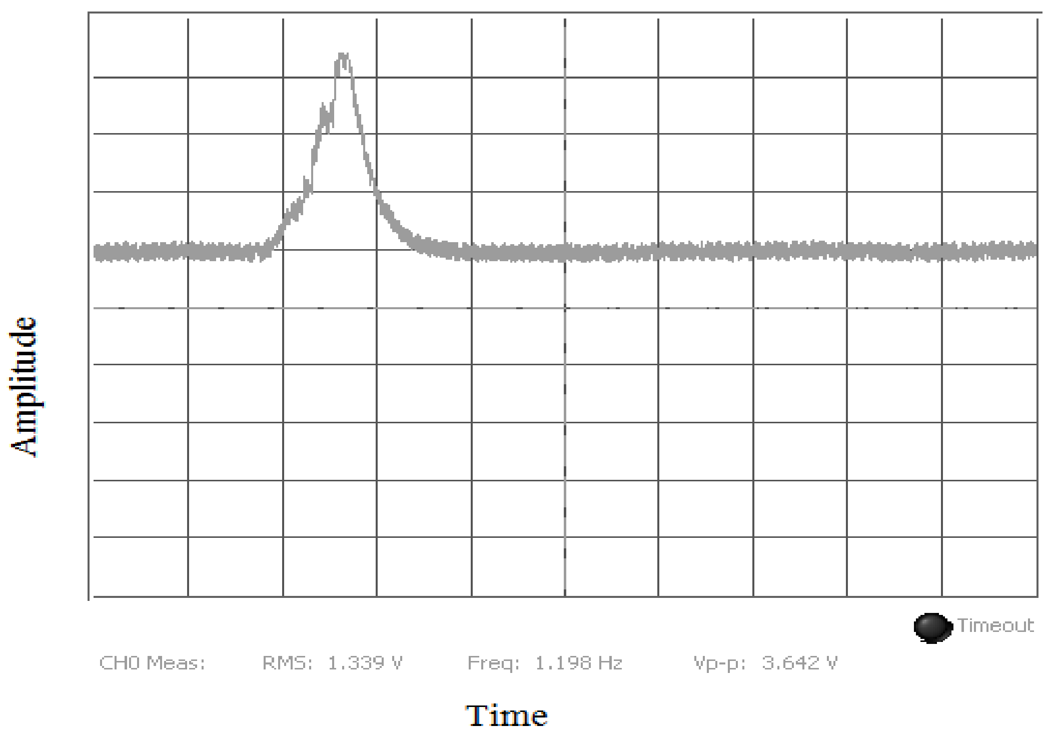

Figure. 5.9 Envelopment of SEMG signal acquired from fabricated sensor.

5.2 Response of Sensor against Prolonged Muscle Contraction

Flexor carpi radialis forearm muscle is a major muscle to operate wrist. Response of developed SEMG sensor against prolonged muscle contraction is observed for 1 min and 25 sec. Detail is shown at Table 5-1.

Table 5-1 Response of developed SEMG sensor against prolonged carpi radialis muscle contraction

Ser No	Muscle Condition	RMS Value
a.	Muscle relax	32.38 mV
b.	Muscle response at initial 5 Sec	3.06 V
c.	Muscle response at prolonged contraction during 1 min	Swing between 1-2 V
d.	Muscle response at prolonged contraction after 1 min and 25 sec	1.089 V

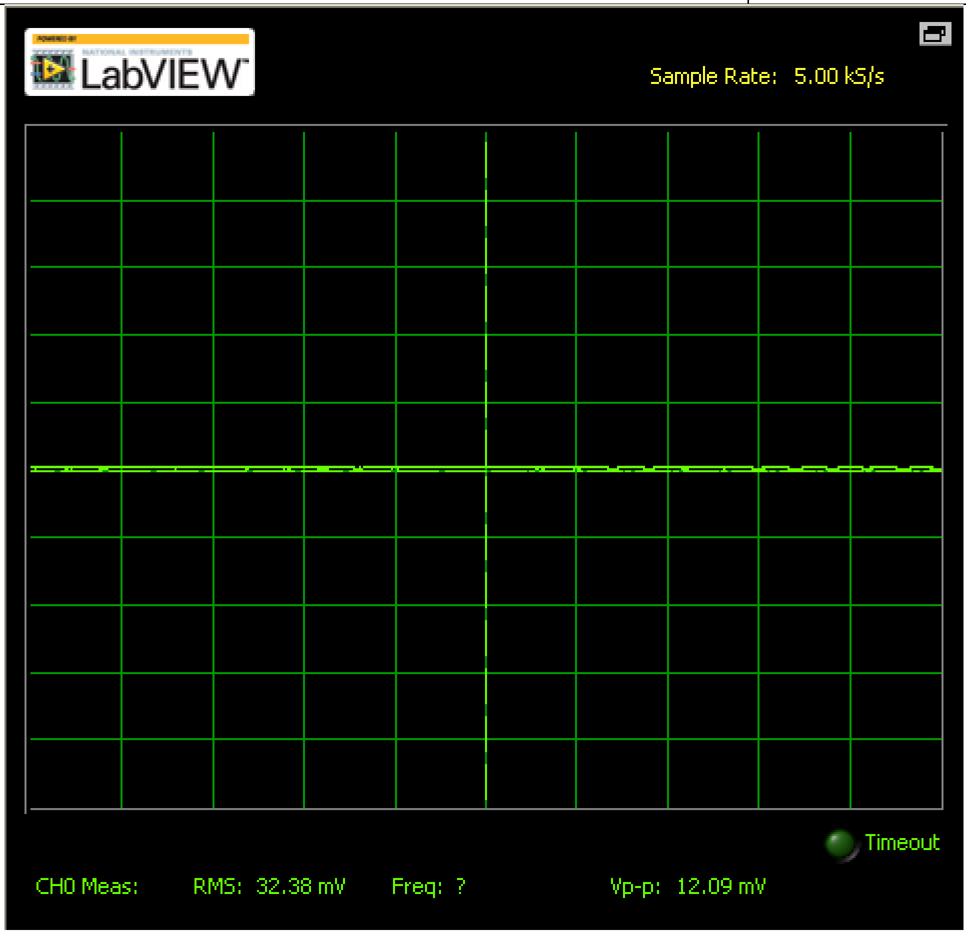

Figure. 5.10 Relax muscle response acquired from fabricated sensor.

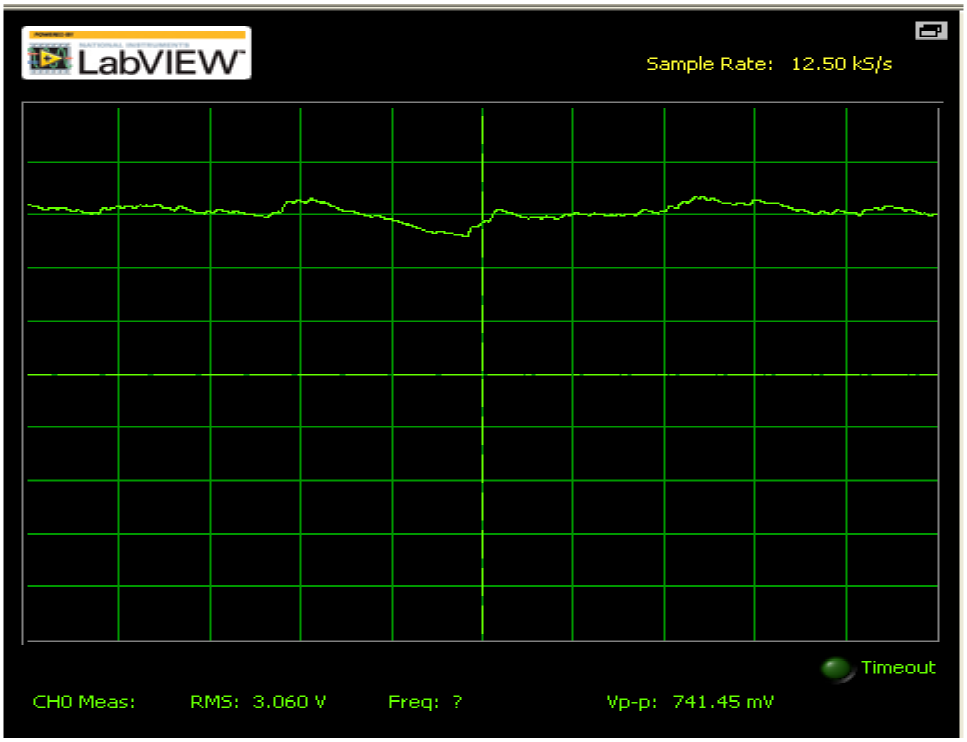

Figure. 5.11 Prolonged muscle response during initial 5 sec from fabricated sensor.

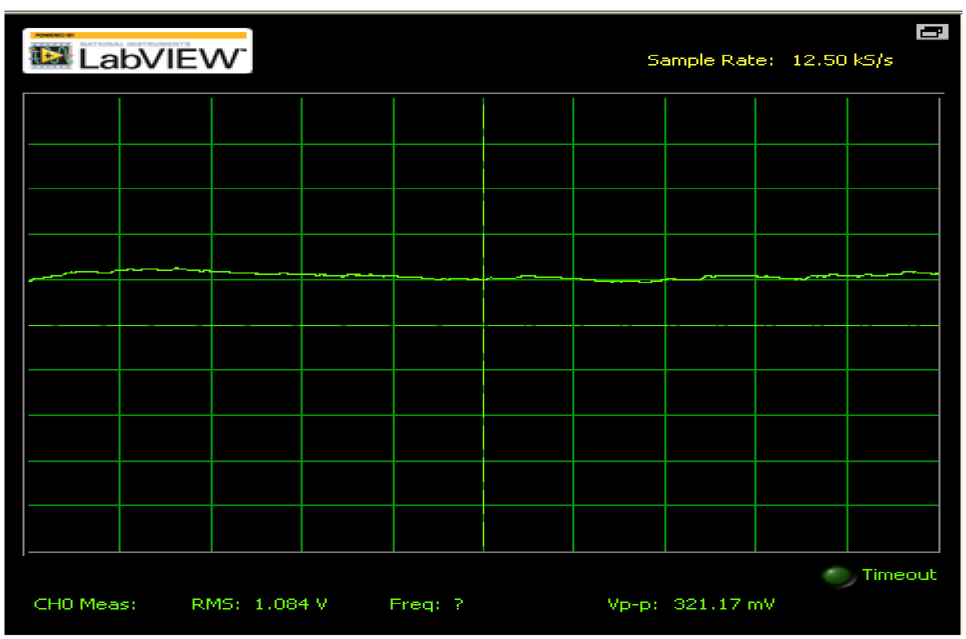

Figure. 5.12 Prolonged muscle response after 1 min and 25 sec acquired from fabricated sensor.

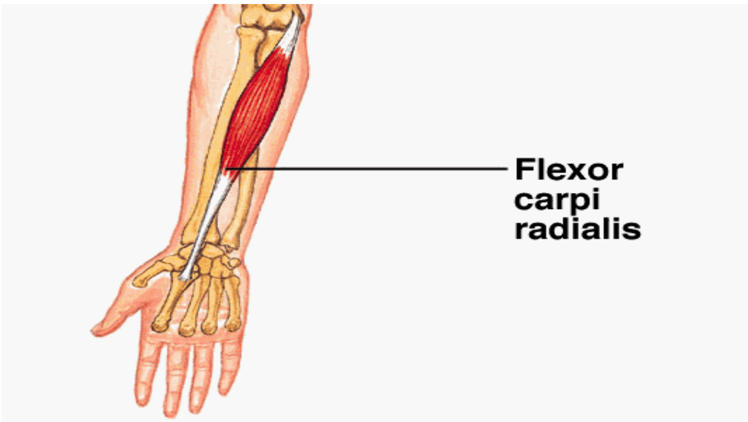

Figure. 5.13 Flexor carpi radialis forearm muscle [17].

5.3 Results of Flexor Carpi Radialis Forearm Muscle

To check the response of developed SEMG sensor against flexor carpi radialis forearm muscle, 5x male subjects were selected having age ranges from 20-38 years. Muscle response of all subjects were checked at 100% MVC. Detail is tabulated at table 5-2.

Table 5-2 Response of carpi radialis forearm muscle at 100% MVC

Ser No	**Subject**	**Amplitude (p-p) value**
a.	Subject-1	3.886 V
b.	Subject-2	2.973 V
c.	Subject-3	3.626 V
d.	Subject-4	2.173 V
e.	Subject-5	3.945 V

5.4 Discussion

An analog signal comprises of components at various frequencies. Highest frequency component present in signal dictates the bandwidth of the signal. As per Nyquist theorem, the sampling rate of the signal must be at least twice of the maximum frequency component present in signal otherwise aliasing will occur [13,34]. In our study, we are more interested to simulate the effect of cut-off frequencies of different low/high/notch filter on FFT and PSD of real single activity source of EMG signal. So frame base operation is chosen in this model. As sampling rate of selected discrete EMG signal R00203 is 10K Hz. So we choose 16384 samples/frame, which also fulfill the criteria (2^N samples) to get FFT of the signal. Normally bandwidth of EMG signal is 20-500Hz [31]. So to get this bandwidth, second order high pass filter (f_c=20Hz) is used, which filtered motion artifacts and baseline noises. For higher frequency components more than 500 Hz, a second order low pass filter (f_c=490Hz) is used. If we analyze figure. 5.1 to figure. 5.3, it is clearly evident that raw EMG signal is effectively processed in the range of 20-500 Hz at the slope rate of -12dB/octave [6]. Furthermore to remove power line noises, notch filtering due to Twin-T notch filter is very obvious in figure. 5.3. Finally, the envelopment of EMG signal can be witnessed in figure. 5.4. As squaring and low pass filtering technique is used in this model for envelopment. Squaring block squares the EMG signal and demodulates the input by using input as its own carrier wave. Resultantly half of the energy of EMG signal is pushed up to the higher frequency and rest is shifted down towards DC. As we keep only lower half of the signal energy, thus scale block (scale=2) will match the final energy of the signal to its original. Down sample block will decimate the signal by factor 'K' and resultantly signal rate will be reduced from F_s to F_s/K [35]. In this model, we have selected K=4, so this block will keep 4^{th} number sample each time and discard 3xsamples each time so resultantly left with 32768 sample points [35]. As frame based operation is being performed in this model, so frame based option along with multirate processing option is selected in this block. So the size of the frame is 16384 samples/frame, which is also multiple of K factor (K=4) [35]. Low pass discrete filter is used to get envelop of EMG signal at 2.34 Hz [5]. Square root block reverses the scaling distortion due to squaring of the signal.

As the main focus of this study, was to design an active SEMG sensor with the help of Simulink model. So discrete transfer function blocks are used instead of digital filters. Best part of this model is that one can visualize the performance of EMG sensor from amplification till conditioning of EMG signal by using online available real EMG data before fabrication of sensor. On successful results of these filter blocks, same RC values are incorporated in hardware circuitry of EMG sensor. Bipolar power supply ±5V is used in circuitry. INA118 Instrumentation amplifier IC is used for differential amplification of SEMG signal, acquired from skeleton muscles through silver electrodes directly connected to INA118 as shown in Figure. 4.15. Other circuitry as shown in Figure. 4.2 to Figure. 4.6 for signal conditioning is incorporated in sensor fabrication. Labview software is used to acquire FFT and PSD of SEMG signal. If we analyze the FFT of filtered signal as highlighted in Figure. 5.7, fabricated sensor has effectively filtered noise component below 20 Hz and over 490 Hz. Furthermore notch filter has removed power line noise components as was evident in Figure. 5.6. If we compare the results of FFT and PSD of Simulink model as in Figure. 5.2, 5.3 and fabricated sensor as in Figure. 5.7, 5.8; both have effectively conditioned EMG signal between 20-500Hz. Power line noises have also been successfully eliminated. SEMG signal strength varies person to person and same can also be inference from the acquired values tabulated at table 5-2 against 5x male subjects at 100% MVC.

5.5 CONCLUSION

The electromyogram (EMG) signal is the biopotential signal generated due to electrochemical reaction took place at junction point because of muscle contraction. EMG signal is very random in nature and is hard to differentiate with other noise signals. So proper conditioning of signal is essential to eliminate unwanted noises. Currently available sensors are very expensive and large in size, so it limits the use while considering EMG signal. The active sensor that has been designed in this work not only reduced the unwanted noises but also amplify the desired EMG signal. Complete conditioning circuit in one small chip. It is cheap and small in size and easy to use in providing input to some microcontrollers for prosthetic control. No thorough skin preparation is required, just wiped the skin and dry electrodes of sensors with any antiseptic (Dettol) and sensor is ready to acquire signal. Developed sensor is indeed proven to be an effective active SEMG sensor for SEMG signal acquisition, its conditioning and amplification. It is indeed another step forward for service of humanity in general and Pakistani nation in particular.

5.6 Future Scope

- SNR may be further improved.
- Size may be further reduced by switching to 4xlayers PCB fabrication instead of 2xlayers.

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Completion Certificate

It is to certify that the thesis titled "Design and fabrication of active SEMG sensor for prosthesis control" submitted by registration no. NUST201362519MCEME35513F, A/O Afzaal Ahmad of MS-78 Mechatronics Engineering is completed in all respects as per the requirements of Main Office, NUST (Exam branch).

Supervisor: ___________

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Date: ____ Dec, 2015